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TITLE OF THESIS: EFFECTS OF ACID GAS TREATMENT AND
VISCOSITY CORRELATIONS ON PSEUDO
PRESSURE DETERMINATION

DEGREE: MASTER OF ENGINEERING

YEAR THIS DEGREE GRANTED: 1990

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UNIVERSITY OF ALBERTA

EFFECTS OF ACID GAS TREATMENT AND
VISCOSITY CORRELATIONS ON
PSEUDO PRESSURE DETERMINATION

BY

STANLEY P. INGHAM

A PROJECT

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN THE PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER OF ENGINEERING

IN

PETROLEUM ENGINEERING

DEPARTMENT OF MINING METALLURGICAL
AND PETROLEUM ENGINEERING

EDMONTON, ALBERTA

SPRING 90

UNIVERSITY OF ALBERTA
FACULTY OF GRADUATE STUDIES AND RESEARCH

THE UNDERSIGNED CERTIFY THEY HAVE READ AND
RECOMMEND TO THE FACULTY OF GRADUATE STUDIES AND
RESEARCH FOR ACCEPTANCE, A PROJECT ENTITLED THE EFFECTS OF
ACID GAS TREATMENT AND VISCOSITY CORRELATIONS ON PSEUDO
PRESSURE DETERMINATION SUBMITTED BY STANLEY P. INGHAM IN
THE PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF ENGINEERING IN PETROLEUM ENGINEERING.

TO MY CHILDREN,
MICHAEL AND PARKER,
WHO ARE THE FUTURE

ACKNOWLEDGEMENTS

I wish to express my gratitude and thanks to Professor Peter M. Dranchuk, under whose supervision this study was carried out. Thanks are also due to Dr. Donald L. Flock, who provided suggestions and assistance for the completion of this work.

Thanks also to Dr. Hemanta Sarma for his encouragement and support during the periods of uncertainty and stress.

A very special thanks to my wife, Christine, for her encouragement and sacrifices and to my family for their patience and understanding which have contributed to the successful culmination of this study.

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NOMENCLATURE

		Field	SI
B	- volume factor	ft ³ /scf	m ³ /ms ³
c	- compressibility factor	psia ⁻¹	kPa ⁻¹
C	- integration constant		
d	- inside pipe diameter	in	cm
D	- inside pipe diameter	ft	m
h	- reservoir thickness	ft	m
k	- permeability	md	um ²
M	- molecular weight	lbm/lb-mole	g/g-mole
φ	- porosity	%	%
ρ	- gas density	bm/ft ³	kg/m ³
P	- pressure	psia	kPa
q	- flow rate	STB/D	m ³ /s
r	- radius	ft	m
t	- time	s	s
S	- saturation	%	%
T	- temperature	R	K
μ	- viscosity	cp	mPa-s
Y	- Boltzmann Transform		
z	- compressibility factor	dimensionless	

Subscript

c	- critical property
D	- dimensionless quantity
e	- external border
i	- initial
j	- number reference
o	- oil
r	- reduced property
w	- well bore
wa	- water

ABSTRACT

The purpose of this study was to examine the effect of the existence of acid gases and the use of each of two viscosity correlations (Carr, Kobayashi and Burrows and Dean and Stiel) in the determination of the Pseudo Pressure term^{*}. Three situations were analysed: the first included the use of all available corrections for the presence of acid gases; the second ignored these corrections; the third involved an analysis based upon gas which was acid free. The same approaches were taken using actual gas well test data.

These situations were examined for a group of gases covering the entire pressure range for each of the correlations used. The same study was repeated for actual field tests to determine the effects of the various methods and correlations on the interpretation of the tests.

For the theoretical situation, i.e., the full reduced pressure range, parallel results of viscosity and Pseudo Pressure were calculated for the various treatments of the acid gases. When the results of Pseudo Pressure were calculated from actual tests data, the use of the three acid gas treatments and the two viscosity correlations had a negligible effect on the interpretation of Pressure Transient Analysis test results.

* Pseudo Pressure - The Pseudo Pressure term ($\Psi = 2 \int (P/\mu z) dP$) is primarily used in the calculation of gas flow behaviour in porous media.

CHAPTER I

INTRODUCTION

Understanding gas properties, and predicting their behaviour with greater accuracy are two of the goals of research in the petroleum field. In addition to the economic benefits which result from improvement in the ability to predict reservoir size, to determine maximum production rates, and to size field equipment and processing plants, these studies may also yield a better understanding of reservoir behaviour which will enhance resource management. Pressure Transient Analysis (PTA) is an important tool for understanding the reservoir and its behaviour.

In PTA of gas reservoirs, three methods - Pressure, Pressure Squared, and Pseudo Gas Pressure - are used in solving the Darcy-Continuity equation. The first two methods, the Pressure and Pressure Squared approaches, require simplifying assumptions to solve a non-linear, second order, partial differential equation. Al-Hussainy and Ramey (1966, pp 624-642) did not make these assumptions and introduced the third approach, the Pseudo Pressure solution.

The purpose of this study was to investigate the evaluation of the Pseudo Pressure term by carrying out the following:

1. Determine whether or not the assumption of constancy of $P/\mu z$ and μz is correct and, if so, to determine if there are any limits.

2. Evaluate the $c\mu$ product required in the evaluation of a compressible gas.
3. Evaluate the effects of CO_2 and H_2S on $P/\mu z$, $1/\mu z$ and μc terms.
4. Examine the differences between the Lee, Gonzalez, and Eakin (1966), the Carr, Kobayashi, and Burrows (1954), and the Dean and Stiel (1965) viscosity correlations.
5. Compare predicted Pseudo Pressures using the Dean and Stiel viscosity correlation to those predicted using the Carr *et al.* viscosity correlation.
6. Examine the effects of these viscosity correlations on the interpretation of field tests.

LITERATURE REVIEW

1.1 COMPRESSIBILITY FACTOR FOR NATURAL GAS

An equation of state (EOS) relates a known quantity of gas to fluid density at a given or known pressure and temperature; fluid density is inversely proportional to volumetric behaviour at a given or known pressure and temperature. For real gases, the deviation of volumetric behaviour from its ideal behaviour is expressed by the gas compressibility factor (z-factor). There are several approaches available to predict this behaviour. These include models based on van der Waals forces such as the one proposed by Peng and Robinson (1976), as well as a popular empirical method developed by Standing and Katz (1940).

Although the Standing and Katz method was readily accepted from 1940 until the mid 1970s for all natural gases, it is not particularly suitable for computer applications. Therefore, several mathematical models were created to represent the chart developed by Standing and Katz. Three of the more popular models are Starling (1975), Hall and Yarborough (1973), and Dranchuk *et al.* (1974). The initial Dranchuk *et al.* (1974) model, which used only eight variables, was later modified in a paper by Dranchuk and Abou-Kassem (1975), to increase the accuracy of the z-factor for reduced temperatures below 1.05. Using the modified eleven-variable EOS, the Dranchuk and Abou-Kassem (1975) correlations for the z-factor, became more similar to the correlations presented by Starling and Hall's EOS.

However, the overall performance of the Dranchuk and Abou-Kassem (1975) model is only marginally better than the performance of the Dranchuk *et al.* (1974) model.

One other mathematical representation of Standing and Katz's chart is a correlation developed by Gopal (1977). Although Gopal referenced more popular z-factor models, he presented few arguments to confirm the accuracy of his model. Because the accuracy of Gopal's model is unproven, it was not considered for this study.

Since this study was concerned with the effect of acid gases and viscosity correlations on the development of Pseudo Pressure, only the original Dranchuk *et al.* (1974) EOS was used, even though the Starling EOS, the Hall and Yarborough EOS, and the Dranchuk and Abou-Kassem EOS are acceptable.

The Dranchuk *et al.* (1974) EOS uses the Benedict, Webb and Rubin (BWR) EOS to develop the z-factor correlation. Although the BWR EOS can be quite awkward for general use in the field, the need for lengthy and repetitive calculations do not pose a problem for this study. In a situation in which it is not practical to use a multi-quadratic EOS, a simpler EOS which comprises a two constant cubic equation based upon van der Waal forces may be suitable.

Models such as those presented by Peng and Robinson (1976), Schmidt and Wenzel (1980), and Soave (1972) improved the two constant cubic equation. While the EOS based upon van der Waal is more accurate than the BWR EOS in predicting PVT behaviour in the vapor/liquid equilibria, it is less accurate in predicting gas densities. Since this study dealt with single phase gas behaviour, the van der Waal EOS was not used.

1.2 GAS PROPERTIES AND CORRECTION FACTORS

The most common and simplest mixing rule used to determine the critical properties for gas mixtures is Kay's Rule which considers the weighted average of the individual gas properties. Kay's Rule was used in this study with one exception. The exception to the use of Kay's rule is the use of Prausnitz and Gunn's rule of mixing in determining critical pressure. Dean and Stiel (1965) recommended the Prausnitz and Gunn method of evaluating critical pressure as it resulted in more accurate viscosity determination.

From the critical properties, one can then determine the reduced properties which are in turn used to determine the z-factor, gas densities and compressibilities as long as the reduced values are within the model's limitation. However, if hydrogen-sulfide (H_2S), carbon-dioxide (CO_2), nitrogen (N_2) or other non-hydrocarbon gases are present in the mixture, an additional correction will be required to match experimental z-factor, densities and compressibilities with the predicted results. Often correction for the presence of these gases is achieved by correcting either the z-factor itself or the properties which are used to predict the z-factor.

Robinson *et al.* (1960), and Wichert and Aziz (1972) believed that in many situations only H_2S and CO_2 gases are naturally present in sufficient quantity to affect gas behavior. The Robinson *et al.* method corrected the predicted compressibility factor by a ratio that was reflective of molar percent of CO_2 and H_2S . Later, Wichert and Aziz (1972) presented three mathematical correlations specific to the three popular z-factor models available at that time for these same gases. There

were, however, some limitations to both of these proposed methods of correcting for these acid gases. Firstly, the Robinson *et al.* (1960) charts are not suitable for computer applications, and if used they require a large datafile. Secondly, the Robinson *et al.* charts were also limited to a maximum combined CO₂ and H₂S concentration of 60%. Finally, neither Robinson *et al.* or Wichert and Aziz presented a correlation to correct for the presence of N₂ gas; in the case of Robinson *et al.*, N₂ gas was included with the methane.

Despite its limitations, the Wichert and Aziz correlation (1972) was the best model to use in this study because it is applicable to computer programming and it provides a greater range of application for H₂S and CO₂ gases than the Robinson *et al.* correlation.

Although N₂ is naturally present in most reservoirs, the abnormally large concentrations which appeared in the sample may have been introduced by poor sampling techniques which allowed air to contaminate the sample. If contamination occurs, fluid analysis will indicate the presence of either O₂ or oxidized hydrocarbons. In many cases, N₂ represents a small proportion of the gas composition. However, to eliminate uncertainty, as well to eliminate the effect of this gas on the EOS, gas mixtures containing large amounts of nitrogen (greater than 10%) were not used.

1.3 VISCOSITY OF NATURAL GASES

Like compressibility, viscosity of natural gases has been studied by many investigators. The three models used in this study for an examination of viscosity correlations are, Carr *et al.* (1954), Dean and Stiel (1965), and Lee *et al.* (1966).

Of these, the Carr *et al.* (1954) empirical correlation for viscosity appears to be the most popular in the Canadian petroleum industry. However, like the Standing and Katz z-factor chart, it is not readily adaptable to computer application. The Energy Resources Conservation Board (ERCB), however, has provided a program for the Carr *et al.* viscosity correlation in their third edition G-3 manual. The ERCB had also incorporated viscosity corrections for N₂, CO₂ and H₂S gases, as originally presented in the Carr *et al.* (1954) paper. By comparison, no other viscosity models had a similar correlation for all three gases.

Viscosity corrections for H₂S and CO₂ in both the Lee *et al.* and the Dean and Stiel correlations were obtained through the use of the Wichert and Aziz(1972) correlation. The Wichert and Aziz correction factor was already incorporated in the correction to the gas properties, which had in turn corrected the EOS prediction. Both viscosity correlations require knowledge of gas density, which was calculated from values generated by the Dranchuk *et al.*(1974) EOS.

Comparison of these three viscosity correlations was started by Chan and Dranchuk(1985). Although the results remain unpublished, the Chan and Dranchuk

study was regenerated in this study for the purpose of understanding the effects of different viscosity correlations in the treatment of acid gases.

It was not the objective of the Chan and Dranchuk (1985) study nor was it the objective of this report to determine which of the three models is the most accurate. As well, the use of the Carr *et al.* (1954) viscosity correlation as the basis of comparison should not be construed as an indication that this correlation is the most accurate. The same caution is also expressed in the examination of the Pseudo Pressure determined with the use of the two viscosity correlations. In generating Pseudo Pressures, only the Carr *et al.* and the Dean and Stiel viscosity correlation were used due to high computer running cost.

The Dean and Stiel (1965) viscosity correlation may have a greater range of application than Lee *et al.* (1966) because the Lee *et al.* study compared four gases in a limited number of temperature and pressure ranges. The Dean and Stiel correlation also has greater application than the Lee *et al.* viscosity correlation because Dean and Stiel considered both polar and non-polar gases.

1.4 ANALYSIS OF THE DARCY-CONTINUITY (DIFFUSIVITY) EQUATION

The three methods of gas transient analysis involve the Pressure, the Pressure Squared, and the Pseudo Pressure methods. As pointed out by Al-Hussainy and Ramey (1966), and later by Aziz *et al.* (1976), each method requires assumptions

about the reservoir properties. In all cases the reservoir is assumed to have the following properties:

- i. isotropic and homogeneous;
- ii. isothermal;
- iii. constant thickness throughout;
- iv. horizontal;
- iv. porosity, permeability and other formation properties are independent of pressure;
- v. gas with constant properties;
- vi. laminar single phase fluid flows at a constant velocity;
- vii. negligible effects from gravitational forces on the fluid;
- viii. the formation fully penetrated by a vertical well; and
- ix. the well open hole completed.

Based on these simplifying assumptions, a second order, non-linear partial differential solution was derived as shown in Appendix I. However, even making all these assumptions, the equation cannot be solved in its present form. Using flow, boundary conditions and other simplifying assumptions, one can formulate the various Pressure, Pressure Squared and Pseudo Pressure solutions as indicated in Appendix I. Boundary conditions which are applied in the analysis of most PTA tests are: $q = 0 @ r = r_e$ and $P = P_i @ t = 0$. In addition, the solution also is based on the assumption that the pressure transient acts as if it were in an infinite reservoir that has a wellbore of zero radius.

Horner PTA analysis, which accounts for the majority of analysis, is a two-rate test where the second rate is zero. The principle of super-position is used in this study to allow a multi-rate analysis.

To solve gas PTA by the Pressure solution, it is assumed that the gas acts as a slightly compressible fluid (liquid). The same solution can be obtained if the product of $P/\mu z$ is treated as a constant.

In the Pressure Squared solution, it may be assumed that the gas is ideal, that viscosity is independent of pressure, and that the non-linear term of $(dP/dr)^2$ that is formed approaches zero rapidly; alternatively, the Pressure Squared solution can be solved by assuming that the product μz is constant.

In tight or highly damaged reservoirs, $(dP/dr)^2$ may not approach zero rapidly and therefore should not be eliminated. This, however, means that the Pressure Squared solution cannot be solved because $(dP/dr)^2$ is a non-linear term. Dranchuk and Quon have proven that, in this situation, it is possible to solve the Pressure Squared equation without eliminating the $(dP/dr)^2$ term, by defining new transform variables.

Although these simplifying assumptions readily allow for the solution of the diffusivity equations, there is a question whether or not the assumption that $P/\mu z$ or $1/\mu z$ are constant is correct, and, therefore, whether or not these simpler solutions should be applied.

1.5 PSEUDO GAS PRESSURE

This section describes the development of the Pseudo-Pressure term. Since Al-Hussainy and Ramey (1966) first introduced their Pseudo-Pressure, there has been a debate as to whether or not the additional calculation, used to create greater accuracy, is warranted in view of the greater simplicity of the Pressure or Pressure Squared method. Aziz *et al.* (1976) recommended which of the two methods would be the most suitable in specific situations.

Aziz *et al.* (1976), indicated that by comparing the initial and final Pseudo Pressure with the appropriate Pressure or Pressure Squared curve, one can select the curve which best matches test response. If neither plot generates an appropriate curve for pressure range of interest, then, neither the Pressure nor Pressure Squared method will suffice.

Dranchuk and Quon pointed out that the additional simplification of neglecting the non-linear term of $(dp/dr)^2$ in the Pressure Squared method was not necessary to solve the diffusivity equation. Large errors may be introduced in the Pressure Squared solution if the $(dp/dr)^2$ term is inadvertently neglected. To avoid the problem, Dranchuk and Quon defined two transform functions to evaluate the $(dp/dr)^2$ term. Depending on which variable is a strong function of pressure (either p or both p and μ) a specific transform function could be used. Dranchuk and Quon further indicated the error that could be expected, should this term be neglected. This error applies only to the differential equation and is not necessarily the same error which would appear in the final solution.

Zana and Thomas (1970) modified Pseudo Pressure by considering the effects of CO_2 and H_2S on real gas flows. The results were given as tables of Pseudo Pressure, with specified amounts of these gases. However, since Zana and Thomas used the Robinson *et al.* model to correct the gas property, their solutions were limited to a maximum concentration of CO_2 and H_2S of 60%.

Tiab (1984), tried to extend the effect of CO_2 and H_2S concentration by using the Wichert and Aziz correction for gas properties. Tiab, unfortunately, used the Gopal EOS to generate Z factors. The limitations of the Gopal EOS were discussed in Section 1.1.

In 1987, Klins and Biterge used the following correlations to develop a semi-analytical solution to the Pseudo Gas equation: the Dranchuk *et al.* (1974) EOS, the Wichert and Aziz correction for CO_2 and H_2S , and the Lee *et al.* correlation for viscosity. The resulting solution did not require numerical integration. For this study, similar attempts were made to develop a semi-analytical solution using the Dean and Stiel viscosity correlation, but these attempts were unsuccessful. In this study Pseudo Pressure was numerically integrated, using the trapezoidal rule.

In all studies, including this study, the main objective is to increase accuracy in the determination and understanding of Pseudo Pressure in its application to PTA. Whether the Pseudo Pressure was determined by a semi-analytical solution or by numerical integration was not relevant to this study, provided that Pseudo Pressure was determined accurately.

Although it is related to Pseudo Pressure, Pseudo-Time as defined by Agarwal, has not been considered in this study. Pseudo Time was first applied to aid

in the PTA analysis of hydraulic fractures. The application has since been extended to build up PTA of tight gas reservoirs and wells with changing storage coefficient. Since the wells which were analyzed were not tight and the time for which storage effects occur were limited, the use of pseudo time was not a concern in this study.

As was mentioned earlier in this report, in PTA of gas reservoirs, three methods - Pressure, Pressure Squared, and Pseudo Pressure - are used in solving the Darcy-Continuity equation.

Aziz, Mattar *et al.* (1976) compared the three approaches and determined the conditions under which the Pressure and Pressure Squared methods best approximate the Pseudo Pressure solution; they also determined the possible limitations of these two approaches. They also investigated the effects of using average properties on the resulting solution. However, neither Aziz *et al.* nor Al-Hussainy and Ramey, conducted any tests to determine whether or not the conditions which were assumed to be constant were actually constant. Nor did they discuss the effects either of acid gas or of the various viscosity correlations on the Pseudo Pressure determination.

Aziz *et al.* (1976) used the Carr *et al.* (1954) model for viscosity in calculating the Pseudo Pressure. The Carr *et al.* model, however, is not easily adaptable to computer application as it requires storage of many data points. Also, some form of interpolation between points is required. The Energy Resource Conservation Board (ERCB) has developed and published a program that addresses these two problems. Firstly, the program enables one to use the Carr *et al.* graph in computer applications; secondly, the ERCB (1979) uses the Lagrange method for interpolation between data points. The Dean and Stiel (1965) model, however, is suitable for computer application because it is an algebraic expression.

CHAPTER II

2.1 MODEL CONDITIONS

In determining the various objectives of this study, computer programs for viscosity, z-factor, compressibility, density and Pseudo Pressure using Pseudo Reduced Pressures (p_{Pr}), were developed or obtained from available sources.

Integration for Pseudo Pressure was accomplished by using the trapezoidal rule with a P_r step interval of 0.05. Development of a semi-analytical solution for Pseudo Pressure, like the one presented by Klins and Biterge, was not possible due to the combination of empirical relations used in this study.

The conditions were tested for a range of reduced pressures and temperatures for various gas mixtures and for actual pressure transient data available from the ERCB. The reduced temperature range varied from 1.05 to 3.00 with reduced pressure ranging from 0.20 to 20.00. Actual test data Pseudo Pressures were determined at the obtained pressure response and reservoir temperature.

Thirty gas mixtures were considered for this study. They consisted of ten sweet dry gases, seven dry sour gases, four sweet wet gases, and nine sour wet mixtures. For the purpose of this study, wet gases were defined as those mixtures containing more than five mole percent of butane or heavier hydrocarbons. Although this may be less than an exact definition, these gases are most likely to produce

condensate. This definition provided a guideline permitting the classification of gases without knowledge of reservoir or surface pressures and temperatures. The gas composition of these mixtures is provided in Appendix II and at the beginning of each result output.

Computer programs for the Carr *et al.* viscosity correlation and for the z-factor were provided in available programs in the Gas Well Testing Manual 3rd edition and in a published paper by Dranchuk *et al.* (1974), respectively. In addition, the Carr *et al.* correction for N₂, H₂S and CO₂, was also accounted for in the viscosity correlation while the z-factor program was modified slightly to include compressibility determination. The other programs utilized were the Dean and Stiel viscosity correlation and the Wichert and Aziz correction for the acid gases H₂S and CO₂.

Programs used to determine $P/\mu z$, μz , $c\mu$, and Pseudo Pressure are provided in Appendix III, along with computer results.

Some of the values generated by some of the programs were also plotted for comparison, using the University of Alberta Tell-a-Graf, Graphic Software Package.

2.2 LIMITATIONS

As stated earlier, results generated for all correlations used the same limitations as those established by the z-factor correlation. These limits were:

$$1.05 < T_r < 3.00; \text{ and}$$

$$0.20 < P_r < 20.0.$$

For T_r less than 1.05 and in particular in multi-phase regions, both the EOS and the Dean and Stiel viscosity correlation showed considerable deviation from actual behaviour. Problems can be minimized if the simpler cubic van der Waal EOS formula is used, as it predicts fluid behaviour more accurately in the multiphase region.

Dean and Stiel recommend against using their viscosity correlation when the fluid has a reduced density greater than 2.0. This condition will occur at extremely low temperatures, or for gases within the two-phase region, or at extremely high pressure. In this study, high pressures, i.e., P_r greater than 15, resulted in this limit being exceeded, but it was assumed that the relationship would be reasonably accurate for the purpose of comparison. Dean and Stiel had stated that "viscosity of a liquid at a higher reduced density depends on both density and temperature".

For the Carr *et al.* viscosity correlation, similar limitations exist. These authors expressed concern about accuracy when T_r approaches 1.0 and when P_r is less than 1.0. In this region, the calculated ratio μ/μ_i is "expected to have the greatest uncertainty". Additionally, an upper limit of 860 degrees Rankin was set by the ERCB. In the analysis of the gas mixtures, this limit was exceeded, and again it was assumed that the correlation is reasonably accurate for the purpose of this study. Assumptions such as these are not uncommon as some well test analysis programs like those of Fekete make the same assumptions.

The same reservation should be expressed in accepting available correction factors for N_2 , CO_2 , and H_2S as these correction factors are only approximate. Carr

et al. stated that such corrections only "indicate the direction and magnitude of error introduced and are hypothetical in nature...".

In the Lee *et al.* viscosity correlation, no limits were expressed. However, since the Lee *et al.* study was based on the results of only four gas mixtures, through a temperature range of 100 to 340 degrees F and a pressure range of 100 to 8000 psi, the study was extremely limited. No attempts were made by Lee *et al.* to predict the viscosities of gases at extremely high pressure, or gas viscosity within the two-phase region. The authors indicated that the success of their viscosity prediction hinged on accurately predicting the gas density. It is assumed in the present study that gas density was accurately predicted.

CHAPTER III

3.0 DISCUSSION

Aziz *et al.* concluded that in certain conditions either the Pseudo Pressure solution or the Pressure solution can be used, as these solutions provide similar results: Aziz *et al.* also concluded that when certain other conditions prevail either the Pseudo Pressure solution or the Pressure Squared method can be used as these solutions provide similar results. Aziz *et al.* based their calculations on the assumption that the Pseudo Pressure solution is the most accurate. Mathematically and logically, the Pseudo Pressure solution is probably the most accurate method as it is the most consistent, that is, it requires the fewest assumptions. However, this does not guarantee that it will be the most accurate solution in all cases.

It can be argued that some simplifying assumptions in the Pressure or Pressure Squared solutions may compensate for other parameters not accurately described in the solution. This argument is philosophical, with no one solution resolving the problem; it is best to study the actual field results to determine which theory is correct. In this study, as in the study conducted by Aziz *et al.*, it was assumed that the Pseudo Pressure solution is the most accurate solution available.

Examination of the products P/μ_z , $1/\mu_z$ and $1/c\mu$, was carried out on four gas mixtures, at four reduced temperatures. Each of these mixtures reflected extreme diversity in composition. The four mixtures were methane, a 53/47 percent split

methane/hydrogen sulphide mixture, mixture 19 (sometimes referred to as the wet mixture) with the following molar composition:

C1	-	67.18	nC5	-	0.66
C2	-	12.11	iC5	-	0.67
C3	-	12.23	C6	-	0.41
nC4	-	3.95	C7	-	0.19
iC4	-	1.60	C8	-	0.25
He	-	0.01	N ₂	-	0.60
CO ₂	-	0.14	H ₂ S	-	0.00

and mixture 23 (sometimes referred to as a wet sour mixture) with the following composition:

C1	-	36.60	nC5	-	1.12
C2	-	6.65	iC5	-	1.28
C3	-	7.74	C6	-	0.63
nC4	-	4.44	C7	-	0.33
iC4	-	1.84	C8	-	0.00
He	-	0.00	N ₂	-	1.32
CO ₂	-	2.40	H ₂ S	-	35.73

While the gas products were plotted for the four gases using the Dean and Stiel viscosity correlation, viscosity and Pseudo Pressure were generated for 30 different mixtures over similar pressure and temperature ranges, using two or more methods. The results of these calculations are presented in the Supplemental volume of this study.

Gas mixture viscosities were determined by all three available correlations: Carr *et al.*, Dean and Stiel, and Lee *et al.*. To examine the effects of the acid gases on viscosity, three conditions (treatments) were tested - using the available acid gas corrections, neglecting the acid gas calculated correction, and providing an analysis based on an acid free gas.

Pseudo Pressures for the gas mixtures were generated using the Carr *et al.* and the Dean and Stiel viscosity correlations. The same three conditions that were tested in the determination of viscosity were also tested in the determination of Pseudo Pressure.

3.1 ANALYSIS OF PRESSURE AND PRESSURE SQUARED ASSUMPTIONS

The results of the $P_r/\mu z$ values calculated with the program in Appendix III were correlated on Cartesian co-ordinates as a function of reduced pressures (See Fig 1). To investigate the trend of results, some of the same data was correlated on log-log co-ordinates (See Fig 2). Likewise, the inverse products of μz were plotted against reduced pressure on Cartesian (Fig 3) and log-log (Fig 4) graphs.

The results of this study indicate that the product, $P_r/\mu z$, which is normally assumed to be constant (Appendix III), is not in fact constant. The results indicate that the Pressure solution method should not even be used in PTA of gas reservoirs.

Even at high pressures $P_r/\mu z$ is not constant, nor can it be approximated as a constant. Figure 1 indicate that when a combination of low temperatures and high pressures occurs, $P_r/\mu z$ is the least sensitive to changes. By looking at the log-log graph in Figure 2, it can be seen that this product is not constant. Thus, even though $P_r/\mu z$ is relatively insensitive to change at high pressure and low temperatures, it would be a mistake to approximate it as a constant.

Figure 2 illustrates that the product $P_r/\mu z$ plots almost linearly against reduced pressure on both sides of the discontinuity, in a logarithmic relationship. As the temperature increases, the point of discontinuity also increases, so that ultimately the discontinuity disappears.

When Aziz *et al.* applied the pressure solution, they determined the arithmetic average of pressures and then determined the gas properties using this arithmetic average. Use of this methodology requires caution because the assumed $P_r/\mu z$ product is not linear. For small pressure changes, a simple arithmetic average often suffices. However, for larger pressure ranges, the use of a logarithmic average (equation 3.1) is recommended.

$$[P_r/\mu z]_{\text{avg}} = 10^{\left[\frac{\log(P_r/\mu z)_i + \log(P_r/\mu z)_f}{2} \right]} \quad (3.1)$$

The use of a logarithmic average is recommended, particularly at low temperatures, when P_r is between 1.0 and 2.0.

As in the Pressure solution, the Pressure Squared assumption with the product $1/\mu z$ being constant (Supplemental Volume), is equally incorrect. While the logarithmic plot of the $1/\mu z$ product (Fig4) appears to indicate that the product may be a constant, Cartesian plots (Fig 3) illustrate that this is not the case. The z-factor in

the product $1/\mu z$ dominates this function at low pressures and low temperatures just as it did in the product $P_r/\mu z$. However, unlike the Pressure solution, the product $1/\mu z$ is less sensitive to temperature. As the pressure increases, the temperature differences between the solutions become less important. Therefore, where changes in temperatures would affect the Pressure solution, they would have less effect on the Pressure Squared solution.

The usage of an average product would have greater application in this case for all conditions except one, namely, gases at low temperatures. Because the z -factor dominates the product $1/\mu z$, only the logarithmic average should be applied at low temperatures.

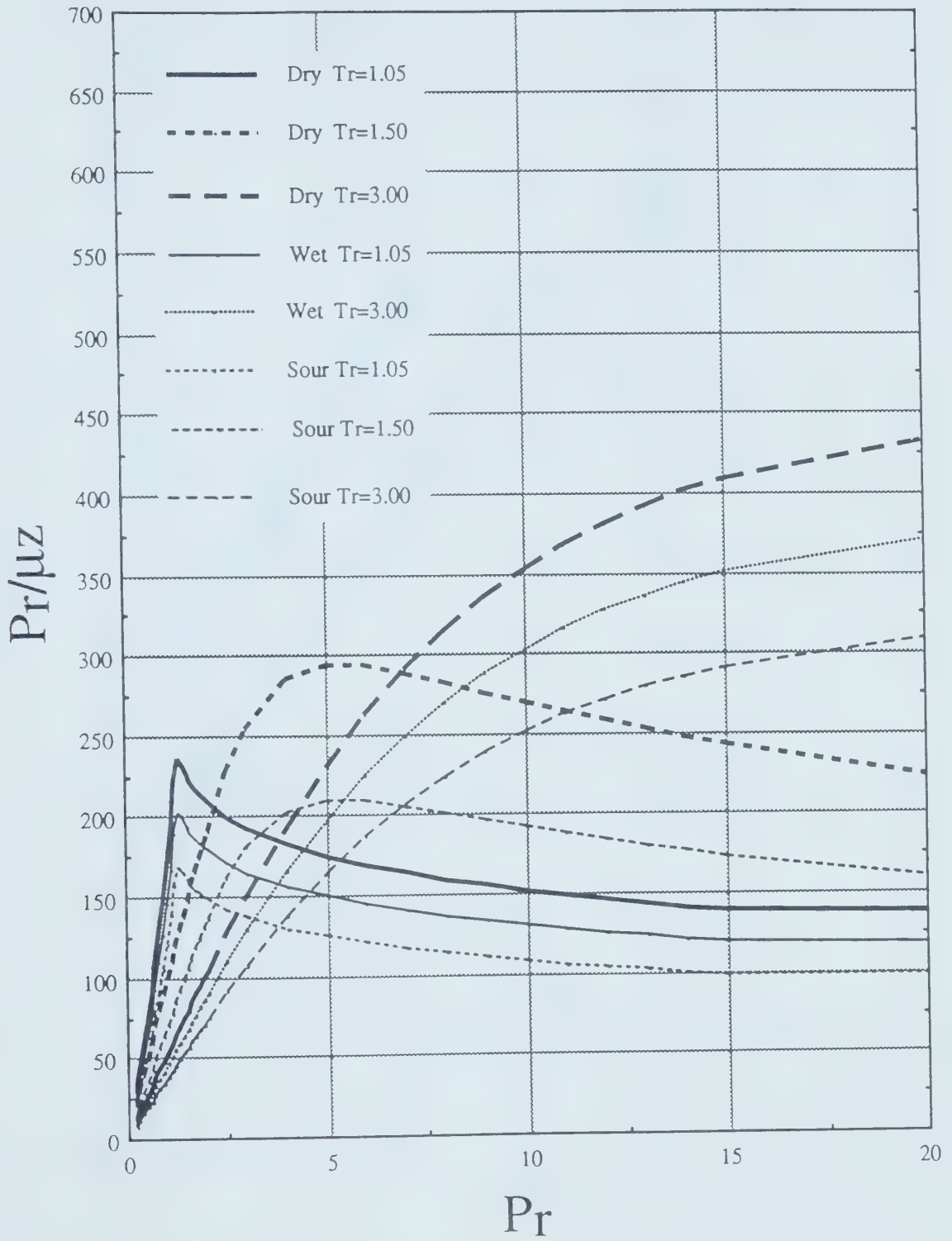


Figure 1.

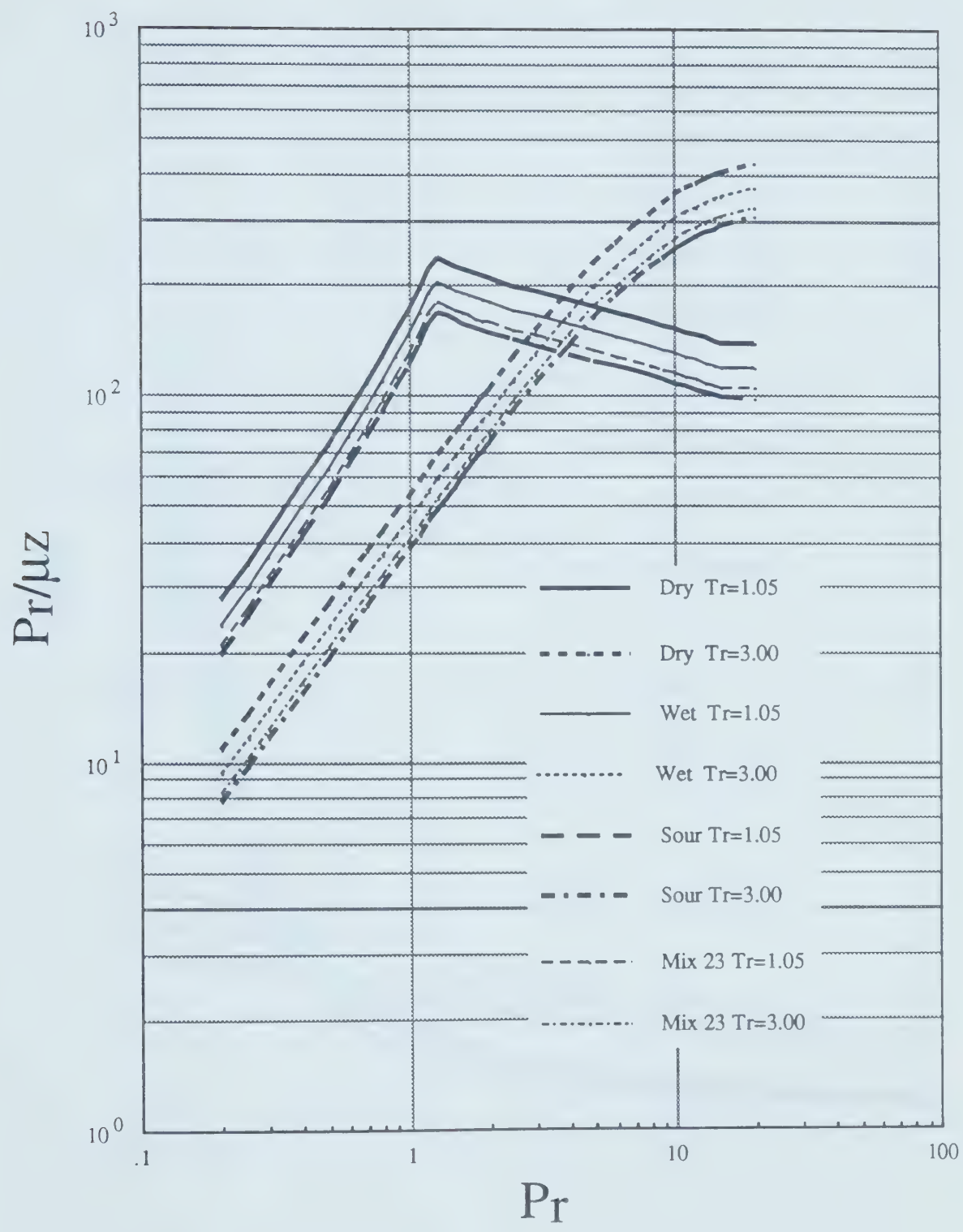


Figure 2.

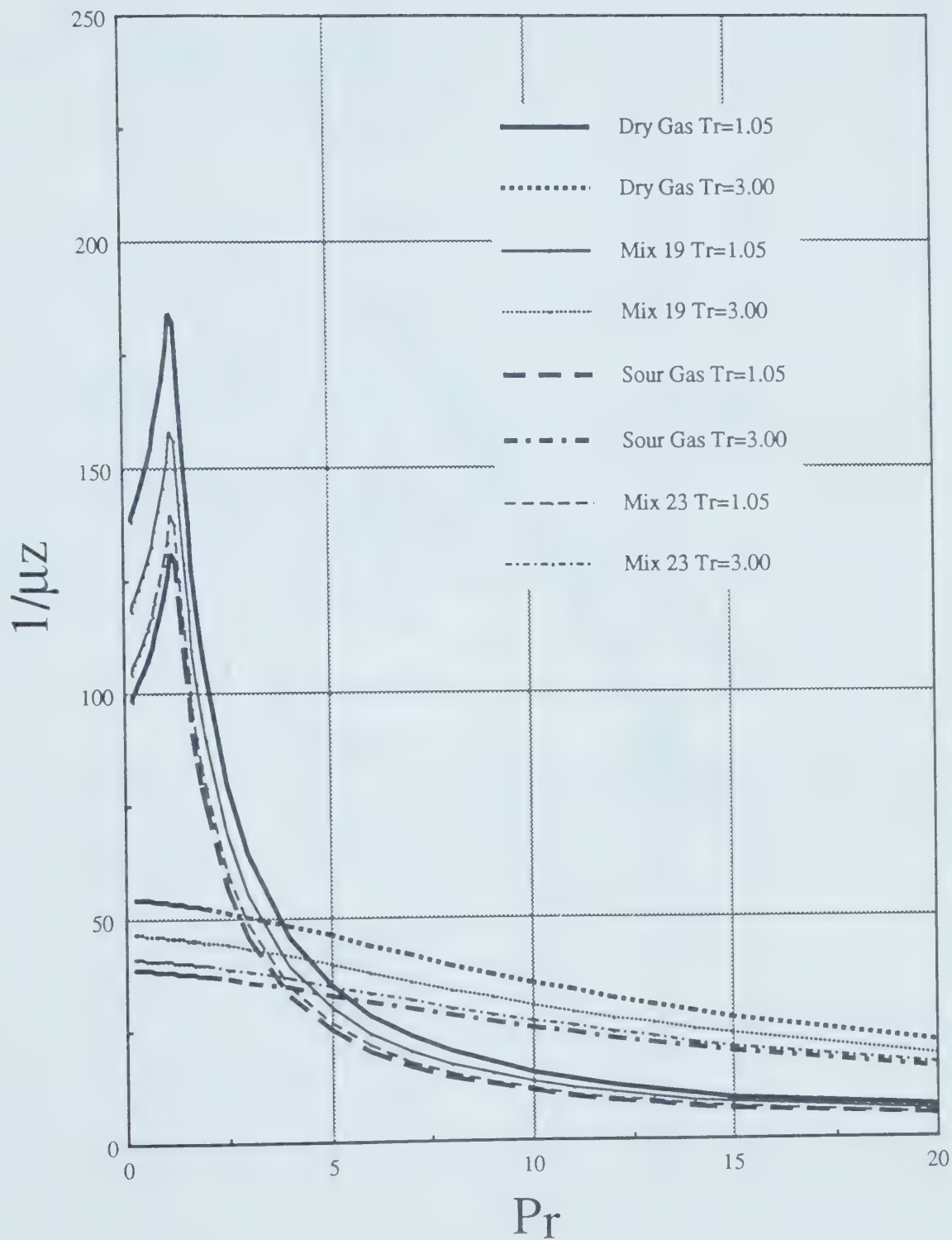


Figure 3.

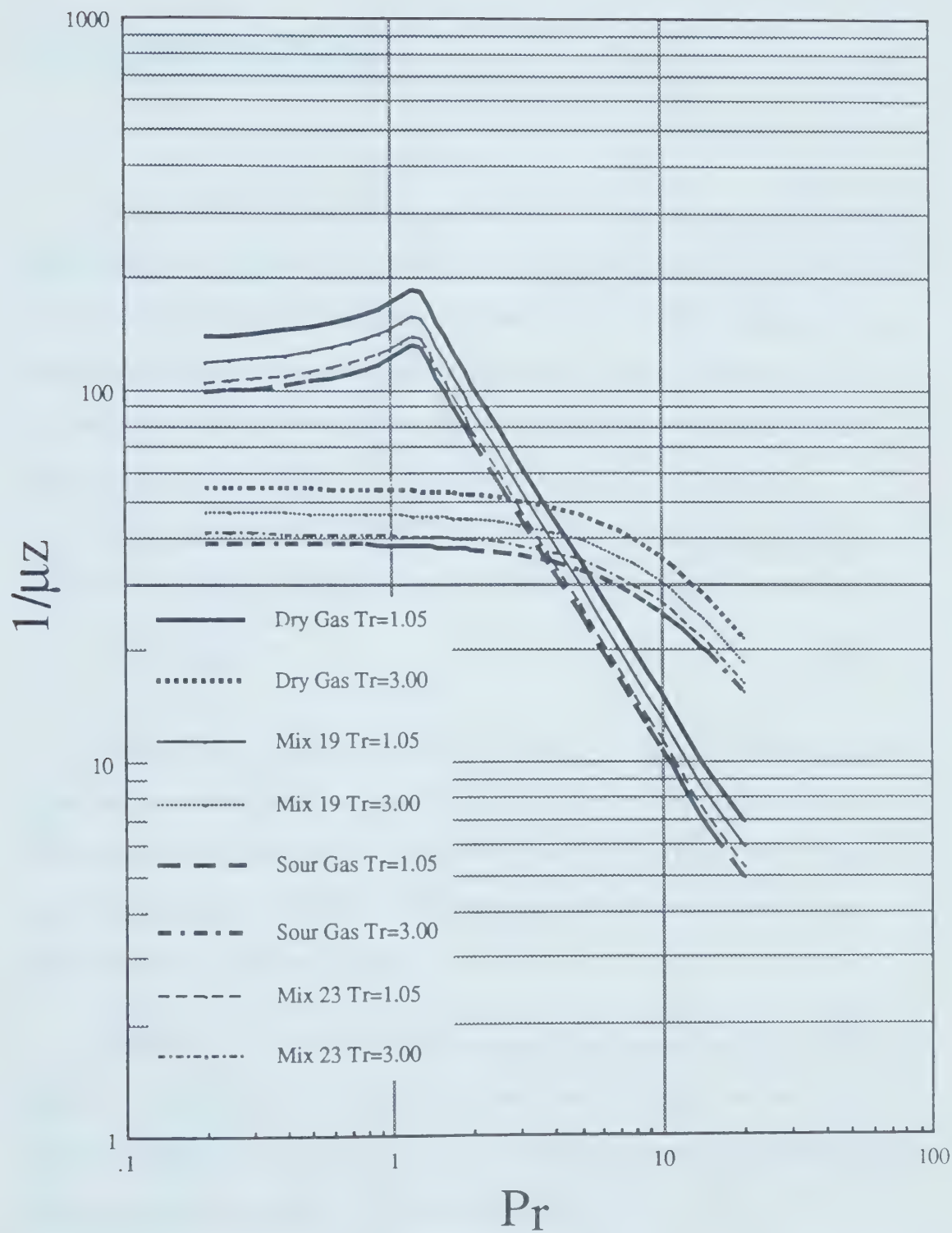


Figure 4

3.2 ANALYSIS OF $c_r\mu$ PRODUCT

Compressibility is defined in equation 3.2. The domination of the z-factor in the calculation of compressibility (Equation 3.2), was first observed by Mattar *et al.* By using the Dranchuk *et al.* (1974) EOS, Mattar *et al.* were able to generate reduced compressibility versus a reduced pressure correlation. This plot differed from that previously published by Trube, in that it mathematically generated the slope dz/dP instead of relying on interpolation. Therefore, Mattar *et al.* concluded that compressibility generated by the EOS should better predict the compressibility of fluids because compressibility generated by EOS is less subject to physical bias.

$$c = \frac{1}{P} - \frac{1}{z} \frac{dz}{dP} \quad (3.2)$$

However Figs 5 and 6 show that in the region where the function $c_r\mu$ appears to approach a constant, $c_r\mu$ is not in fact a constant. Fig 6 illustrates the dominance of the z-factor in the product $c_r\mu$. Mattar *et al.* reported this effect in their comparison with Trube's findings. In Fig 5, the Cartesian plot of this function does not show this problem due to the plot's scaling.

In addition, as in the previous cases, a simple arithmetic average will often be sufficient to evaluate the gas property when small pressure ranges are investigated. However, if the pressure range is large, only a logarithmic average should be applied if accuracy is to be maintained. This recommendation does not apply for low temperature mixtures ($T_r < 1.05$) and reduced pressures between .8 and 2.0, due to the large discontinuity. In this range, actual PVT data or another EOS should be used in

order to accurately predict gas density and fluid viscosity. Then, a determination can be made as to which method, either an analytical method using another EOS, or actual data, will apply.

Aziz *et al.*, also indicate in their study when $c_r\mu$ should be evaluated, i.e., at an average condition or initial condition. As discussed in the previous paragraph, the arithmetic average method will suffice when the range of pressure investigation is small, but the logarithmic average method would be more accurate.

As demonstrated in Fig 7, if the pseudo gas equation is used, then, the product $c_r\mu$ appears to stabilize quickly to a constant. However, upon closer examination the $c_r\mu$ product appears to reach a constant only at a low temperature and for a short pressure range. In addition, as in previous examinations, the Log-Log plot of the product $c_r\mu$, Fig 8, illustrates that the function still retains characteristics similar to those illustrated in Fig 6. Therefore, even though the function appears to stabilize quickly with the use of Pseudo Pressure, similar limitations will still apply as with the previous pressure vs. $c_r\mu$ plot.

Although it is still common to find the use of the product $c_r\mu$ in PTA, and the consequent difficulty of determining where to evaluate the product properly, it is recommended that Pseudo Time be used wherever possible. Agarwal, using the same logic as Al-Hussainy and Ramey had used in developing the concept of Pseudo Pressure, defined the integral Pseudo Time for gas PTA. Although not a true integral, the integral does account for changes in $c_r\mu$ product with respect to time at the corresponding pressure. This eliminates any difficulty in determining the point at which the product of $c_r\mu$ should be evaluated.

However, as previously discussed, caution should still be exercised if the gas is examined within the two-phase region. Extension of the Mattar *et al.* compressibility study, Fig 6, illustrates that the observed inflection will become more predominant as the temperature decreases. When the gas enters the multi-phase region, the term dz/dP will be undefined, thereby dominating the compressibility function. Again, it is recommended in this situation that either actual PVT fluid analysis or compressibility determined by a different EOS, for example van der Waal's EOS, be used.

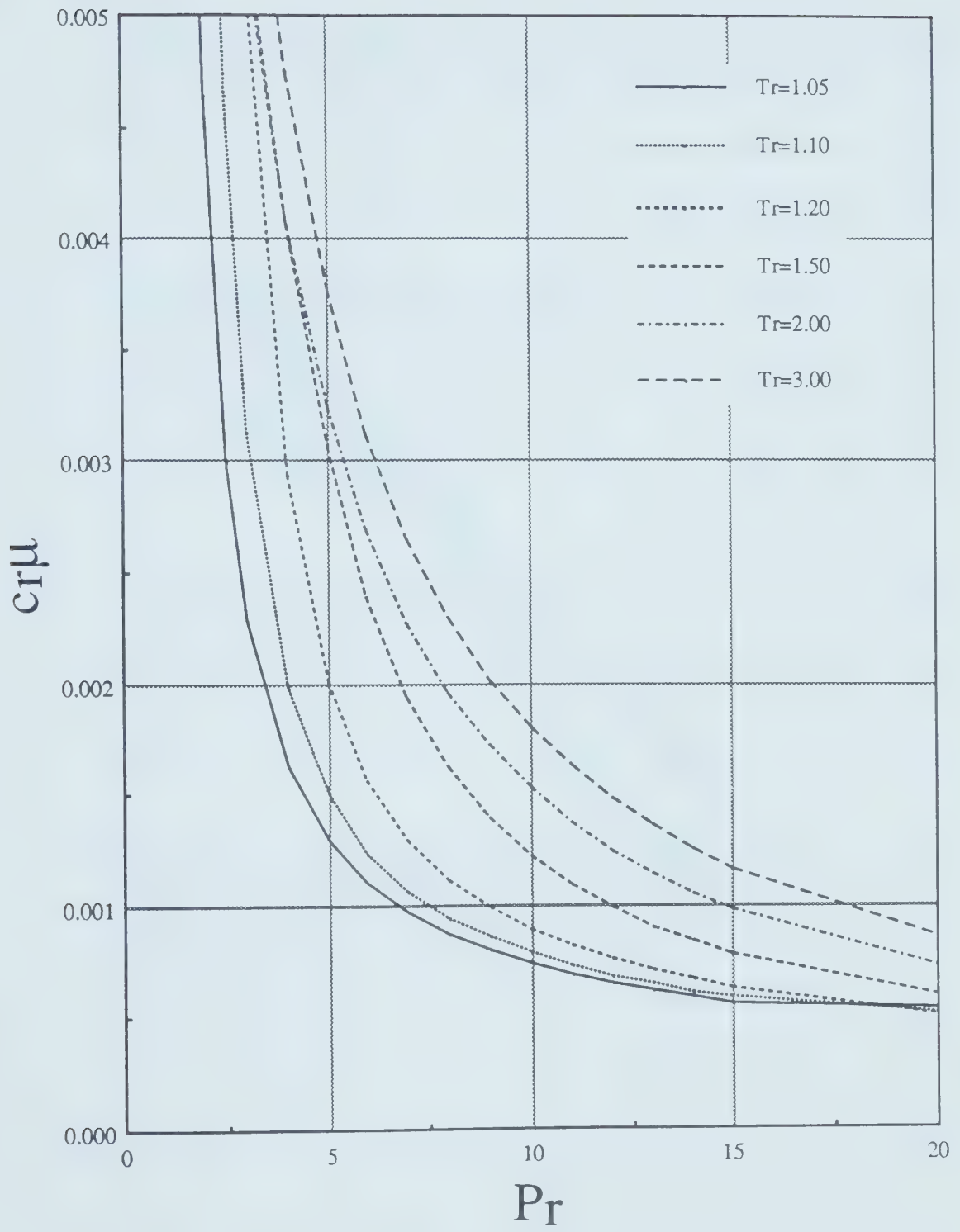


Figure 5.

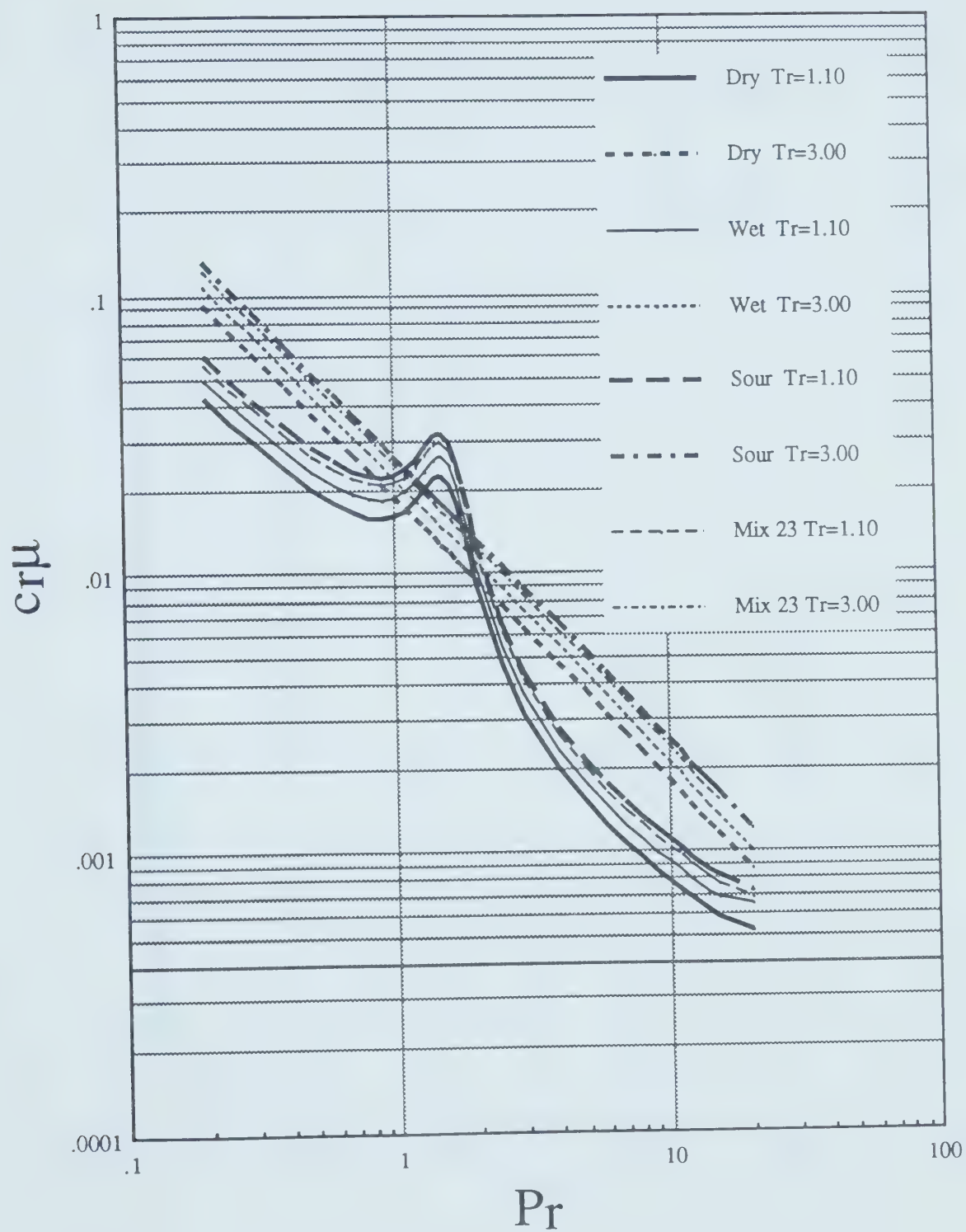


Figure 6.

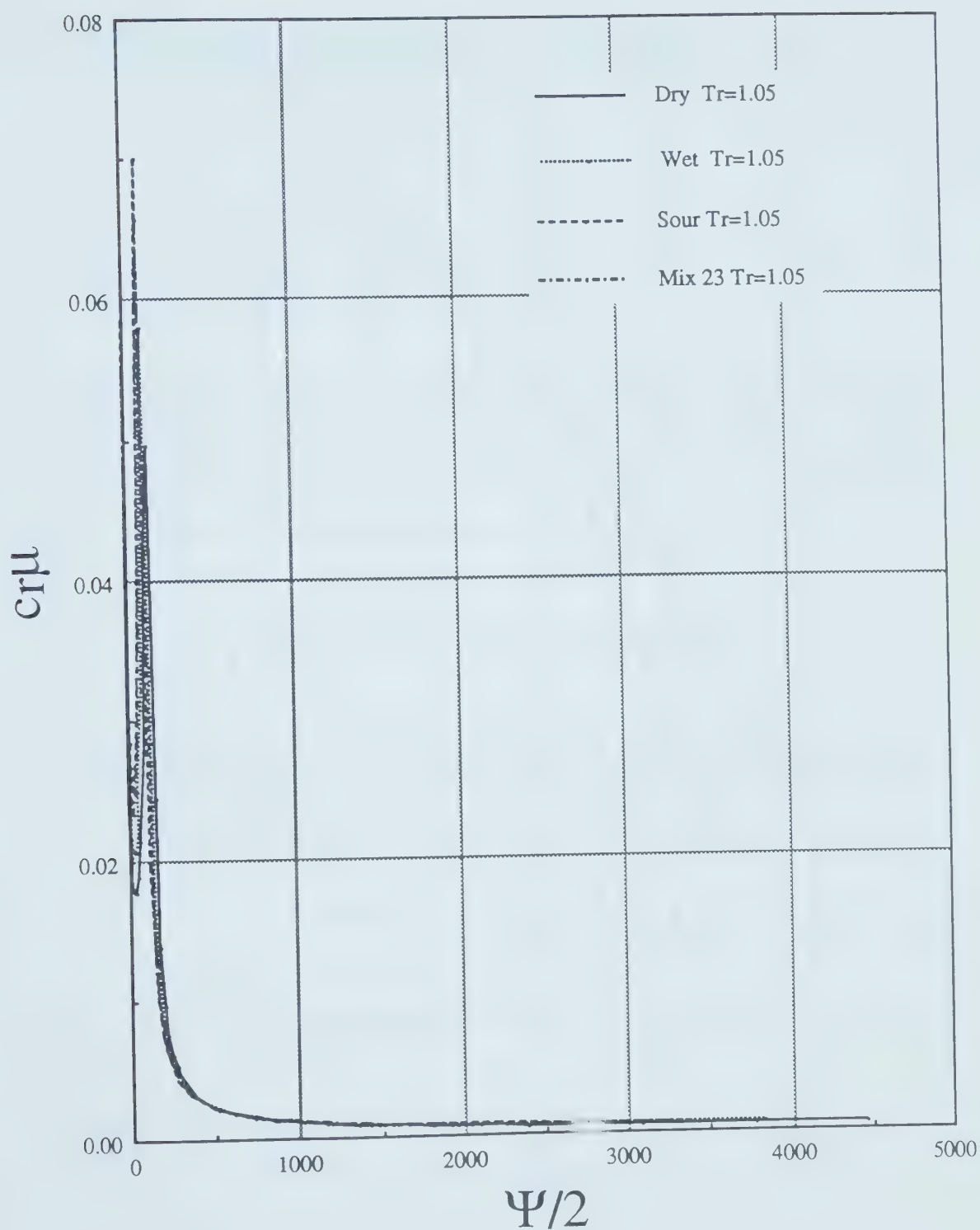


Figure 7.

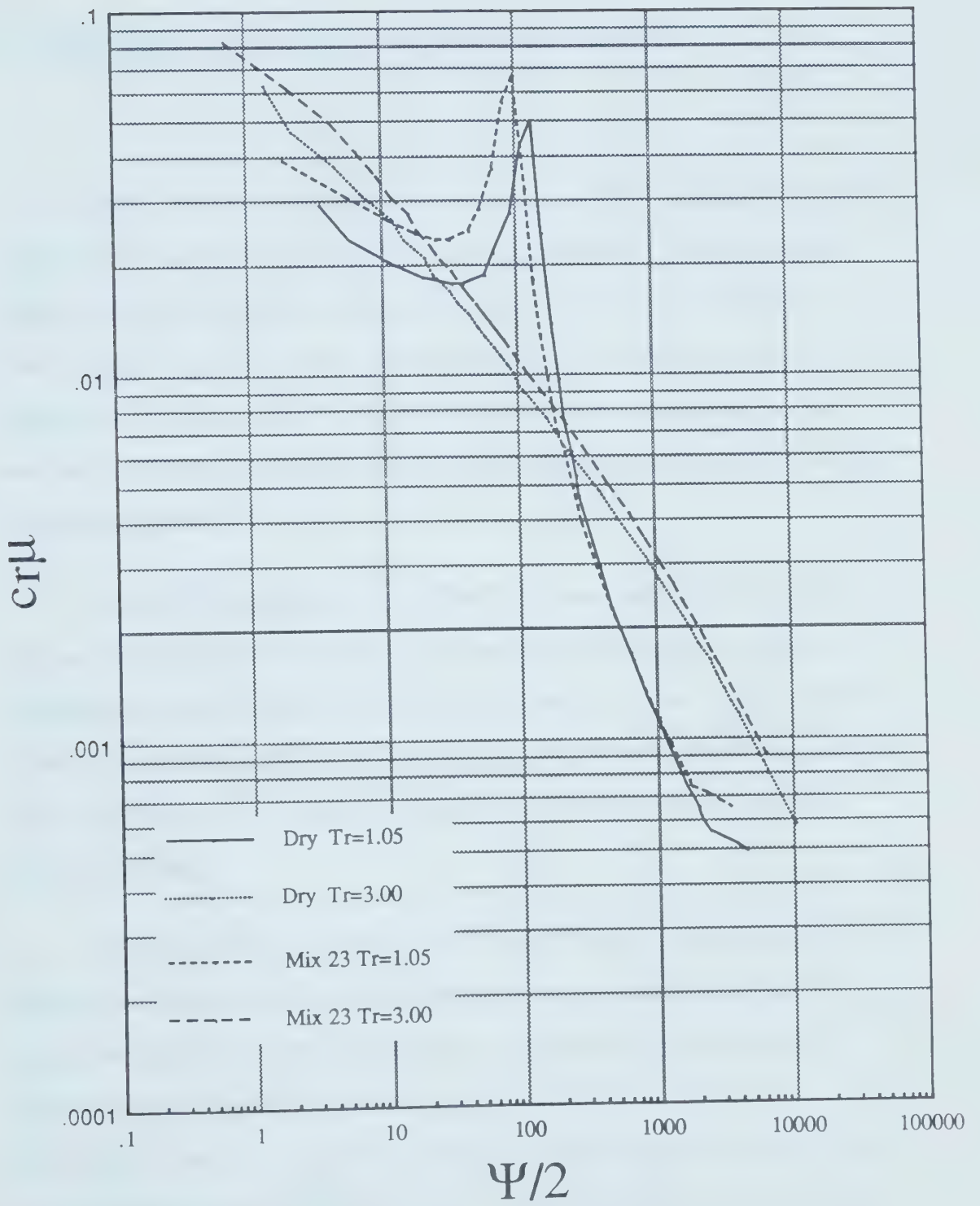


Figure 8.

3.3 ANALYSIS OF H₂S AND CO₂ ON THE GAS PRODUCT

Several authors have attempted to correct the gas PVT behaviour for mixtures containing acid gases (H₂S & CO₂) to those predicted by EOS. Two correction factors have been used in this study: the Wichert and Aziz acid gas correction, and Non-hydrocarbon gas correction within the Carr *et al.* viscosity correlation. Correction of the Dean and Stiel and the Lee *et al.* viscosity correlations, for the presence of acid gases, was achieved by correcting the gas density using the Wichert and Aziz correlation.

CO₂ and H₂S gas treatment were handled in three ways - treatment "A", allowing for all correction factors; "B", eliminating these correction factors; and, "C", providing the analysis based on acid free basis. The type of method used referred to the viscosity correlation. Method 1 used the Carr *et al.* viscosity correlation, method 2 used the Dean and Stiel viscosity correlation and method 3 used the Lee *et al.* viscosity correlation.

In all cases, by examining the gas products $P/\mu z$, $1/\mu z$, and $1/c\mu$, the function relation curve characteristic shape was retained throughout the complete pressure range at each specific temperature. Although the similarity of the curves is not apparent from an examination of the curves plotted in Fig. 1, 3, and 5, an examination of the Log-Log correlations (Fig. 2, 4, and 6), indicates that the curves do run parallel or nearly parallel to each other. The only exception to this rule was the plot of $c\mu$ product versus Pseudo Pressure (Fig 8). In this plot, the difference in gas composition results in a crossing of the curves at the low temperatures, rather

than a parallel plot. An examination of the effect of the gas correction may explain this phenomenon.

If the gas composition is constant throughout the formation, the correction factors are constant regardless of changes to pressures or temperatures. For viscosity, as predicted by Carr *et al.* (1954), the gas correction factor is constant as shown in the ERCB program used in Appendix IV. However, the z-factor, compressibility and densities, used in the calculation of gas viscosities by Dean and Stiel and by Lee *et al.*, is not corrected directly for H₂S and CO₂. Instead, the Wichert and Aziz correction factor, ϵ_3 , which is a constant correction factor, is used to correct the critical properties used in the determination of c , μ , and ρ .

When the Wichert and Aziz correction factor is applied, the critical properties of the mixture are shifted. This results in the shifts in the reduced pressures and reduced temperatures. In this study, with the exception of Fig 8, the reduced pressures and temperatures were held constant to show the effects of CO₂ and H₂S on viscosity correlation and Pseudo Pressure.

For Pseudo Pressure, the results from method 1, using treatments A, B and C, and the results from method 2 using treatments A, B, and C, differ respectively by a constant. A similar relationship was observed in the changes in viscosity. This suggests the conclusion that, whatever correlation is used, when the data are processed in the same way, the results will differ only by a constant.

However, as pointed out previously, and as indicated by Fig 8, actual field test data may not show this particular parallel response due to the presence of acid gases. When the reduced pressure and reduced temperature changes are due to the

shift in critical properties, the z-factor will be changed, thereby also affecting compressibility and density. Since the z-factor curves are not parallel, any shifts caused by the gas correction factor will not result in a parallel solution. At low temperatures and pressures, the effects of this shift will be the greatest, while at high temperatures and pressures such effects will be negligible. This can be seen in Fig 8, and is indicative of the result one expects to see in actual test results.

3.4 EXAMINATION OF VISCOSITY CORRELATIONS

This study is not a comprehensive study of the accuracy of available viscosity correlations, but rather an exploration of the effects of three treatments of acid gases on the viscosity results. The calculations of viscosity were made using viscosity correlations developed by Carr *et al.* (1954), Dean and Stiel (1965), and Lee *et al.* (1966). Correction for acid gases was carried out using the correction factors found in the Carr *et al.* viscosity correlation and by using the Wichert and Aziz z-factor correction which corrects gas density. Both Dean and Stiel and Lee *et al.* use density corrected by the Wichert and Aziz model.

Although in this study the examination of the accuracy of the various models was not considered, a comparison of the methods was made to better understand differences in the results. The results of each calculation were compared with the results obtained using the Carr *et al.* method. The use of this method as the basis for

comparison should not be construed as an acceptance of the position that the Carr *et al.* model is more accurate than any other.

All gas viscosity correlations react in a similar fashion to changes in pressures, temperatures, H₂S and CO₂. The overall trends are the same for all the models. As pressure increases, viscosity increases; as gas gravity increases, so does gas viscosity; as acidity of the gas increases, viscosity increases; as temperature increases, viscosity decreases. The rate of change to viscosity is also less at these higher temperatures. The exception to temperature changes occurred at low pressures, i.e., less than 1.5: viscosity increases when reduced temperature increases. This is not surprising as this behaviour had also been shown in the correlations made by Carr *et al.*(1954) and by Lee *et al.* (1966). This information helps to explain the differences between the Pseudo Pressures arrived at when the various correlations are used.

In this study, the different treatments of the acid gases resulted in parallel solutions when the Carr *et al.* viscosity correlations were used, and the same was true of the solutions obtained when the Dean and Stiel viscosity correlations were used. The Lee *et al.* method gave different results, in that the solutions were not parallel with each other.

By treating H₂S and CO₂ differently, i.e., by including all correction factors, by neglecting the correction factors, or by providing an analysis on an acid free basis, the viscosity results differed by a constant for all temperatures and pressures when the Dean and Stiel method was used. When the Carr *et al.* viscosity results for the three treatments were analyzed, the results differed by a constant for all pressure ranges as long as the temperature did not vary; there was a constant difference for

each temperature. Thus, while the constant was different at each temperature and for each gas mixture for Carr *et al.*, the constant in the Dean and Stiel model remained the same for each gas mixture irrespective of the temperature. The Lee *et al.* results showed a different behaviour, viz., correction occurred in one direction only. The lowest difference, whether positive or negative, existed at the lowest pressure.

An examination of the EOS explains the differences between the viscosities. Both the Dean and Stiel and the Lee *et al.* methods require knowledge of the gas density at a specific temperature and pressure. In this study density was determined by using the Dranchuk *et al.* (1974) EOS. Although knowledge of the gas gravity, reduced pressure and reduced temperature was necessary to calculate viscosity using the Carr *et al.* viscosity correlation, EOS was not necessary in the present study because the digitized tables of viscosity values provided by the ERCB were used. Interpolation between values in the table was achieved using the Lagrange interpolation method. However, as in the Trube presentation, much of the original data was smoothed to correct for any possible experimental errors and to present a graph appealing to the eye.

By using the Dranchuk *et al.* EOS, both the Dean and Stiel and the Lee *et al.* methods showed a sinuous difference between their viscosity correlation and that of Carr *et al.*. In other words, the difference increases as reduced pressure increases, then suddenly decreases, only to increase again.

In his unpublished work, Dranchuk notes that at low reduced temperatures, $T_r = 1.05$, as reduced pressure increases, the slope dP/dV decreases to a minimum value, then starts to increase again. Since gas density is inversely proportional to the volumetric behaviour, a similar relationship between dP/dV and $dP/d\rho$ holds true.

As the reduced temperature increases, the differences between the volumetric behaviours also decrease. That is, the effect of the multi-phase characteristic, the dew point or bubble point line, is reduced until a single changing dP/dV slope is observed.

The increase in temperature has a similar effect when the differences between the viscosity results using the Carr *et al.* viscosity correlation, the Dean and Stiel viscosity correlation and the Lee *et al.* viscosity correlation are compared. As temperatures increase, the differences between the viscosity results from the three correlations decrease. However, the differences between the Carr *et al.* correlation and the Dean and Stiel correlation were generally smaller than the differences between the solutions reached using the Carr *et al.* and the Lee *et al.* methods. This was particularly the case for low temperature, high pressure gases containing large amounts of CO₂; in these cases, the differences between the Carr *et al.* and the Lee *et al.* methods were greater than 100 percent, as opposed to an 8 percent difference between the Carr *et al.* and the Dean *et al.* methods. The greatest deviation occurred near and above the Lee *et al.* pressure limit of 8000 psi.

3.5 COMPARISON OF THE RESULTS OF PSEUDO GAS PRESSURES

In summary, comparison of the Pseudo Pressure results obtained by using the Carr *et al.* correlation with those obtained by using the Dean and Stiel correlation (Appendix V), results in the following conclusions. As temperature increases, the difference between Pseudo Pressures generally decreases, for sweet gases, and for gases that are wet or contain H₂S. For gases that contain a high concentration of CO₂, the difference generally increases as temperature increases.

In addition, the characteristics noted in the viscosity comparison are similar to the characteristics found in the Pseudo Pressure comparison. These characteristics are the constant difference due to the different treatment of acid gases and the sinusoidal fluctuation in the difference between the Pseudo Pressure using Carr *et al.* and the Dean and Stiel viscosity correlation. Considering the Dean and Stiel model only, the difference remained constant irrespective of the temperatures.

In all cases, fluctuation in the difference occurred at low temperatures. However, as with viscosity, these fluctuations decreased as temperature increased. Even with mixtures containing high concentrations of CO₂, such fluctuations were non-existent at the high temperatures. This indicates that, as with viscosity, the Pseudo Pressure determination is dominated by the EOS.

Although the only variable in the determination of Pseudo Pressure was the viscosity model, the differences obtained differed from those obtained in the viscosity comparison. The difference between the Pseudo Pressures is not solely the result of

the inverse relationship of viscosity. Such inequality between the differences obtained in the viscosity correlation as opposed to the differences in Pseudo Pressure are the result of smoothing effects in the integration of the Pseudo Pressure.

3.6 INTERPOLATION OF ACTUAL FIELD DATA

As discussed earlier, the assumptions made within the Pressure and Pressure Squared methods were incorrect, and unless these solutions can be validated by actual field results, such methods should not be considered in PTA of gas reservoirs. Therefore, to compare results obtained by these methods to the Pseudo Pressure solution would be misleading and only confuse the issue. In addition, Aziz *et al.* (1976) have already shown the relationship between the Pressure, Pressure Squared and Pseudo Pressure solutions, with respect to the use of each solution. It is therefore not necessary to repeat the work in this study.

Six actual field build up and deliverability tests were examined and the results are presented in Appendix VI. In all tests, Pseudo Pressures were generated using two viscosity methods as described in the Pseudo Pressure calculations. In the calculation of Pseudo Pressure, the pressure was fixed. This allowed pressure evaluation at different reduced pressures and temperatures. The reduced pressures and temperatures were different because three different acid gas treatments were used. Each gas treatment yielded slightly different critical properties. In summary,

the resulting reduced pressure and reduced temperature is different for each pressure and each gas treatment method. This allowed a full investigation of the effect of different gas treatments.

Since the test data were supplied by the ERCB, it was not possible to scrutinize any information other than that actually provided by the testing company. Experience suggests that factors such as the incorrect reporting of fluid production, information as to well conditioning (particularly if this is a new completion), previous production history, and interference may influence test results. In addition, many tests required either a greater density of readings by rereading the copper strips or by using different and more accurate recorders such as electronic or quartz recorders. Since only a minimal number of readings were provided, it was impossible to fully analyse these tests. However, it was not the purpose of this study to reinterpret the build up tests, but rather to look at the effects of different gas treatments and viscosity correlations. Therefore, it was assumed that all tests were correctly reported.

A typical pressure investigated during these tests was approximately 2 MPa (300psi), while the largest pressure was approximately 11 MPa (1550 psi). This large pressure change resulted in a reduced pressure range of approximately 5.5 - 7.7. Although this range is limited, conclusions were based upon the results of the analysis.

The Pseudo Pressures determined using the Dean and Stiel viscosity correlation (shown in the Supplemental Volume of this work in the Tabulated Results) resulted in consistently lower Pseudo Pressures than the Pseudo Pressures determined using the Carr *et al.* viscosity correlation. The differences between the two sets of results were relatively constant and were in all comparisons less than 0.25

of one percent. Even with the different treatments of the acid gases, the maximum deviation was less than 2.1 percent. However, unlike the results obtained using fixed reduced pressures, the results obtained using the fixed pressures showed that the differences increase as the pressure increases. Although these differences will also increase as the pressure range increases, the effects will not be noticeable on any PTA results.

Since the PTA test results are dependent on the visual analysis of the Horner slope, such differences do not affect the accuracy of the analysis. If the analysis is limited to the region of transient pressure response, the reported range of differences is considerably reduced to 0.03 and 0.15 percent, respectively. However, during the early portion of the test, where PTA by Type Curve analysis was necessary, the difference may result in a slight decrease in the skin and storage coefficient. Because of the approximate nature of type curves, even with derivatives, and the number of curves available, the analysis will not differ even though the differences which occur in this region are greater.

Although the Pseudo Pressures generated using different correlations differ, the solution for each test will be identical as long as the same Pseudo Pressure calculation method is used throughout the pressure range.

Although the different treatments for acid gases yielded different Pseudo Pressures, resulting from the different reduced temperatures, the different treatments did not greatly affect the interpretation of the results. In the cases investigated, the differences between the methods were less than the differences due to the treatment of the acid gases. Where the previous section indicated that the treatment of acid gas

resulted in parallel Pseudo Pressures, the actual test data revealed that the differences increased slightly as pressure increased.

CHAPTER IV

4.0 CONCLUSION

The purposes of this study were to examine the assumption that $P/\mu z$ is constant in the pressure equation and the assumption that $1/\mu z$ is constant in the Pressure Squared equation. The results of the study showed that these assumptions were incorrect. If either the Pressure or Pressure Squared equation must be used, then, a logarithmic average pressure should be used to accurately evaluate the gas parameters, i.e., viscosity, compressibility, and the compressibility factor. A simple arithmetic average pressure should not be used unless the pressure range of investigation is relatively small.

Although the treatment of acid gases appeared to have little effect on the outcome of the solution, this does not mean that correcting gas properties for acid gases should never be considered. In areas other than PTA, correction for these gases to actual PVT behaviour is still necessary. In this study, however, it was not a concern because PTA is concerned with the relationship between pressure differences and not with the pressure itself.

Equally, this study showed that the choice of EOS methods by which Pseudo Pressure is determined has no effect on the PTA solution for the same reasons. However, as indicated above, not all EOS used in PTA will produce parallel

solutions. Limits of the particular EOS may restrict the use of some correlations, for example in the multi-phase region. This study did not address this problem.

The results of the three viscosity correlations differed from each other and the results of the two Pseudo Pressure calculations also differed from each other: these calculations were made using a constant reduced temperature. The magnitudes of the differences were not compared as they varied with the gas composition (refer to Appendixes IV and V). Often, the differences between the methods were constant at high temperatures, regardless of the different treatments for acid gases. This resulted in parallel solutions. At low temperatures, there was fluctuation in the differences between the viscosity correlations because both the Dean and Stiel method and the Lee *et al.* method depend on the EOS in the calculation of viscosity. The differences in the Pseudo Pressure results showed the same type of fluctuation.

When actual field results were analysed, reduced temperatures were different because of the different critical temperatures due to the type of acid gas treatment. The results, although slightly different, also indicated a relative consistency between methods over the pressure range of investigation. These results translated to parallel solutions, and therefore the same answer, even though the difference increased slightly as pressure increases. The three methods of treating the acid gases resulted in greater differences than the differences between the correlations themselves, but these difference were still relatively constant. The difference in the constant is unlikely to noticeably affect any PTA results.

PTA interpretation of actual field tests is limited by two factors, namely, the quality of the data and the skill of the interpreter. Often, data quality is dependent upon the accuracy of the recording device: accuracy may range from 0.5% FSD for mechanical (Amerada) recorders, to 0.005-0.05% FSD for the electronic recorders. In addition, data analysis still requires human interpolation, which in itself may account for greater differences than the differences between the methods or in the treatment in acid gases. Although the advent of automatic curve fitting software and PTA programs may ultimately eliminate the human factor, perfection of this software is still some time away, even though several companies are making remarkable progress.

CHAPTER V

5.0 RECOMMENDATIONS

It is recommended that data from several fields be analysed, each reflecting a completely different fluid composition. In selecting the particular tests, consideration should be given to selecting tests with three distinct flow regimes - storage, transition and transient. Further analysis of these tests will likely confirm the observations in this study.

It is recommended that the Carr *et al.* (1954) correction factor be investigated to confirm its accuracy, and that its results be compared with the results obtained using Wichert and Aziz correction factor.

It is also recommended that a comparison of all viscosity correlations be made to verify the accuracy of existing correlations. Although the use of the Dean and Stiel and the Carr *et al.* viscosity correlations produced little difference in the results of the PTA analysis, as this study has shown there can be extreme differences between the results of these correlations when there are large concentrations of acid gases. These differences can affect metering factors, pipe designs, and fluid flow characteristics, which depend on accurate values.

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APPENDIX I

DERIVATION OF THE PRESSURE AND PRESSURE SQUARED EQUATION.

Fluid flow in a reservoir has been described for many years by the Darcy-Continuity equation. In developing this equation the following conditions had been looked at. These are:

- i. a constitutive equation which describe and relates the shear stress imposed on the fluid to the shear rate; as with the equation which describe the viscosity of a Newtonian fluid at any temperature or pressure:
- ii. the force momentum balance of the system, as described by Newton's second law of motion:
- iii. the conservation of mass:
- iv. the equation of state which relates fluid density to temperature and pressure:
- v. and the conservation of energy.

In addition to these assumptions, it was also assumed that the reservoir or fluid would be:

- i. Single phase fluid with constant property;
- ii. formation which is homogeneous, isotropic and incompressible;
- iii. isothermal and laminar fluid flow;
- iv. reservoir of uniform thickness;

- v. permeability and porosity independent of pressure;
- vi. no cross flow between beds or outside top and bottom boundaries;
- vii. gravitational effect which are minimal.

Considering the radial case only, and the previous assumption, one can derive the Darcy Continuity equation as expressed below;

$$\nabla \cdot \left(\frac{kp^2}{\mu} E \right) = -d \left(\frac{\phi S_r \rho}{dt} \right) \quad (1)$$

where,

$$E = g - \frac{1}{\rho} \nabla P \quad (2)$$

By substituting equation 2 into 1 and expressing it in terms of polar coordinates the following equation can be derived;

$$\frac{1}{r} \frac{\partial}{\partial r} \left(\frac{rpk}{\mu} \frac{dP}{dr} \right) = \partial \left(\frac{\phi S_r \rho}{dt} \right) \quad (3)$$

However, for gas, density can be described as;

$$\rho = \frac{PM_w}{zRT} \quad (4)$$

Therefore;

$$\frac{1}{r} \frac{\partial}{\partial r} \left(\frac{Pk}{rz\mu} \frac{dP}{dr} \right) = \phi S_r \frac{\partial}{\partial t} \left(\frac{P}{z} \right) \quad (5)$$

Klinkenberg however proved that permeability was not constant but varies inversely with pressure. He had expressed permeability of gas flow through a porous media as;

$$k_{app} = k_a \left(1 + \frac{b}{P} \right)$$

Aronofsky and Ferris later indicated that the equation 5 depended more on changes in gas properties than changes in permeability. Therefore Klinkenberg effects were neglected in this study.

By simplifying further, equation 5 becomes;

$$\frac{1}{r} \frac{\partial}{\partial r} \left(\frac{rP}{\mu z} \frac{dP}{dr} \right) = \phi S_r \frac{\partial}{\partial t} \left(\frac{P}{z} \right) \quad (6)$$

CASE 1 PRESSURE METHOD

In this case, gas which is the only fluid present, is treated as a liquid. Two assumption can be made to simplify the equation. First the product of $P/\mu z$ is assumed to be constant, or second the pressure gradient, $(dP/dr)^2$, is assumed to be small. If these were the case equation 6 may be reduced to the same result. The only simplified presented is for case one as follows;

$$\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial P}{\partial r} \right) = \frac{\phi}{k} \frac{\mu z}{P} \frac{\partial}{\partial t} \left(\frac{P}{z} \right) \quad (7)$$

Since the gas is treated as a liquid or a slightly compressible fluid, Z Factor is assumed to be constant, with compressibility being expressed as;

$$C = \frac{1}{P} \quad (8)$$

Therefore equation 7 becomes;

$$\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial P}{\partial r} \right) = \frac{\phi \mu c}{k} \frac{\partial P}{\partial t} \quad (9)$$

By expanding equation 9 to get

$$\frac{\partial^2 P}{\partial r^2} + \frac{1}{r} \frac{\partial P}{\partial r} = \frac{\phi \mu c}{k} \frac{\partial P}{\partial t} \quad (10)$$

CASE 2 PRESSURE SQUARED METHOD

In this method, gas is treated ideally. With this method either the product of $1/\mu z$ is assumed to be constant, or that μ varies independantly with pressure since $z = 1$ (ideal). Knowing this equation 6 can be simplified to:

$$\frac{1}{r} \frac{\partial}{\partial r} \left(r P \frac{\partial P}{\partial r} \right) = \frac{\phi \mu}{k} \frac{\partial P}{\partial t} \quad (11)$$

Letting

$$d(P^2) = 2P dP \quad (12)$$

Equation 11 becomes;

$$\frac{1}{r} \frac{\partial}{\partial r} \left(\frac{r}{2} \frac{\partial (P^2)}{\partial r} \right) = \frac{\phi \mu}{k^2 P} \frac{\partial (P^2)}{\partial t} \quad (13)$$

Again equation 8 still applies so that equation 13 becomes

$$\frac{1}{r} \frac{\partial}{\partial r} \left(\frac{r}{2} \frac{\partial (P^2)}{\partial r} \right) = \frac{\phi \mu c}{k} \frac{\partial (P^2)}{\partial t} \quad (14)$$

Expanding equation 14:

$$\frac{\partial^2(P^2)}{\partial r^2} + \frac{1}{r} \frac{\partial(P^2)}{\partial r} + \left(\frac{\partial P}{\partial r} \right)^2 = \frac{\phi \mu c}{k} \frac{\partial(P^2)}{\partial t} \quad (15)$$

Assuming the pressure gradient $(dP/dr)^2$ is small and therefore neglectable then equation 15 becomes;

$$\frac{\partial^2(P^2)}{\partial r^2} + \frac{1}{r} \frac{\partial(P^2)}{\partial r} = \frac{\phi \mu c}{k} \frac{\partial(P^2)}{\partial t} \quad (16)$$

CASE 3 PSEUDO-PRESSURE

By using Al-Hussainy *et al.* definition of pseudo-pressure

$$\Psi = 2 \int_{P_o}^P \frac{P}{z\mu} dP \quad (17)$$

one can redefine equation 6 as

$$\frac{1}{r} \frac{\partial}{\partial r} \left(\frac{r}{2} \frac{\partial \Psi}{\partial r} \right) = \frac{\phi}{k} \frac{\partial(P/z)}{\partial t} \quad (18)$$

and compressibility expressed by

$$c = \frac{z}{P} \frac{d(P/z)}{dP} \quad (19)$$

therefore

$$\frac{d(P/z)}{dt} = \frac{d(P/z)}{dP} \frac{dP}{dt} \quad (20)$$

$$\frac{d(P/z)}{dt} = \mu c \left(\frac{P}{\mu z} \right) \frac{dP}{dt} \quad (21)$$

$$\frac{d(P/z)}{dt} = \frac{\mu c}{2} \frac{d\Psi}{dt} \quad (22)$$

So that substituting this into equation 20;

$$\frac{1}{r} \frac{\partial}{\partial r} \left(\frac{r}{2} \frac{\partial \Psi}{\partial r} \right) = \frac{\phi \mu c}{k} \frac{\partial \Psi}{\partial t} \quad (23)$$

Expanding equation 23

$$\frac{\partial^2 \Psi}{\partial r^2} + \frac{1}{r} \frac{\partial \Psi}{\partial r} = \frac{\phi \mu c}{k} \frac{\partial \Psi}{\partial t} \quad (24)$$

APPENDIX II

The following mixture composition number applies to Appendix III program only.

DRY MIXTURES										
	1	2	3*	4	5	6	7	8	9	10
C1	95.48	90.98	94.96	91.82	95.73	93.76	97.97	97.15	95.82	96.15
C2	2.57	2.90	1.52	2.81	1.01	0.92	0.14	0.28	0.42	1.52
C3	0.70	1.02	0.69	1.28	0.43	0.18	0.03	0.01	0.29	0.11
nC4	0.20	0.21	0.12	0.32	0.06	0.02	0	0.01	0.11	0.05
iC4	0.08	0.17	0.14	0.32	0.10	0.03	0	0.01	0.13	0.09
nC5	0.04	0.10	0.02	0.09	0.01	0	0	0.01	0.01	0
iC5	0.03	0.15	0.07	0.08	0.03	0.01	0	0.01	0.06	0.04
C6	0.05	0.07	0.03	0.05	0	0	0	0.01	0.01	0.01
C7	0.03	0.04	0.19	0.02	0.05	0	0	0	0.04	0
C8	0.05	0.02	0	0.01	0	0	0	0	0.04	0
CO2	0.20	0	0.05	0.32	0.07	0.10	0.97	0.08	1.07	0.10
H2S	0	0	0	0	0	0	0	0	0.05	0
N2	0.54	4.25	2.71	2.84	2.51	4.98	0.89	2.35	1.88	1.84
He	0.03	0.09	0	0.04	0	0	0	0.08	0.07	0.09

* Values supplied and presented above did not add to 100%. Therefore prior to further use, the mixture were corrected so that the weighted average did add to unity.

The following mixture composition number applies to Appendix III program only.

	SWEET WET GAS MIXTURES				SOUR WET GAS MIXTURES					
	11	12	13	14	15*	16	17*	18	19	20
C1	68.59	79.68	67.18	78.54	58.83	63.41	54.81	49.44	53.11	51.05
C2	15.44	8.66	12.11	9.50	10.54	7.88	17.41	12.60	8.56	12.43
C3	8.27	4.46	12.23	5.53	7.21	5.31	10.07	8.38	1.04	11.63
nC4	2.26	1.35	3.95	1.56	1.72	2.53	3.76	4.15	0.13	2.58
iC4	0.98	0.79	1.60	1.39	0.67	0.79	1.26	1.23	0.36	1.19
nC5	0.28	0.38	0.66	0.42	0.27	0.66	0.34	1.01	0.02	0.23
iC5	0.32	0.40	0.67	0.54	0.22	0.49	0.55	0.77	0.25	0.36
C6	0.10	0.20	0.41	0.27	0.18	0.52	0.60	0.75	0.11	0.12
C7	0.24	0.12	0.19	0.14	0.15	0.22	0.27	0.35	0.10	0.15
C8	0	0	0.25	0	0.10	0.10	0.10	0.15	0	0
CO2	1.58	2.98	0.14	0.26	0.10	0.61	0.48	0.33	26.54	11.40
H2S	0	0	0	0	16.50	9.69	7.62	8.82	4.96	3.10
N2	1.92	0.98	0.60	1.85	3.79	7.70	2.32	12.00	4.75	5.74
He	0.04	0	0.01	0	0.02	0.09	0.01	0.02	0.07	0.02

* Values supplied and presented above did not add to 100%. Therefore prior to further use, the mixture were corrected so that the weighted average did add to unity.

The following mixture composition number applies to Appendix III program only.

DRY SOUR MIXTURES										
	21	22	23	24	25	26	27	28	29	30
C1	69.45	67.05	36.60	75.86	57.55	53.88	54.44	44.26	51.09	43.19
C2	3.55	1.92	6.65	2.11	1.11	9.82	2.96	16.12	11.02	13.61
C3	2.00	0.48	7.74	0.51	0.38	8.98	1.08	9.55	7.20	10.44
nC4	0.90	0.15	4.44	0.28	0.21	3.64	0.47	2.94	2.04	4.16
iC4	0.36	0.10	1.84	0.08	0.13	1.49	0.18	2.71	0.88	2.48
nC5	0.25	0.06	1.12	0.10	0.09	0.79	0.16	0.24	0.25	0.61
iC5	0.23	0.06	1.20	0.11	0.10	0.86	0.17	0.36	0.31	0.87
C6	0.55	0.05	0.63	0.10	0.09	0.40	0.17	0.52	0.09	0.27
C7	0.05	0.03	0.33	0.06	0.06	0.24	1.56	0.39	0.10	0.27
C8	0	0	0	0	0	0.02	0	0.15	0	0
CO ₂	2.01	4.04	2.40	4.90	4.60	2.19	7.25	17.54	5.18	3.00
H ₂ S	13.44	24.96	35.73	12.30	35.07	13.26	29.80	3.46	18.02	19.70
N ₂	7.21	0.99	1.32	3.56	0.61	4.40	1.76	1.75	3.80	1.37
He	0	0.11	0	0.03	0	0.03	0	0.01	0.02	0.03

* Values supplied and presented above did not add to 100%. Therefore prior to further use, the mixture were corrected so that the weighted average did add to unity.

GAS MIXTURE COMPOSITION AND PSEUDO REDUCED PROPERTIES

THE FOLLOWING MIXTURE COMPOSITION NUMBERS APPLIES TO APPENDIX IV, V, AND VI PROGRAMS ONLY.

THE FOLLOWING IS A COMPARISON BETWEEN DIFFERENT METHODS. VISCOSITY VIA-C USES CARR, KOBAYASHI AND BURROW VISCOSITY CORRELATION, WHILE V2A-C USES DEAN AND STIEL VISCOSITY CORRELATION, AND V3A-C USES LEE GONZALEZ AND EAKIN.

METHODS A, INCLUDE ALL CORRECTION FACTORS AVAILABLE, WHILE METHODS B, EXCLUDES THESE CORRECTION FACTORS. METHODS C PROVIDES ANALYSIS ON NON-HYDROCARBON FREE GASES.

ALL DIFFERENCES ARE EXPRESSED IN PERCENT.

MIXTURES LISTED BELOW ARE FOR DRY SWEET GASES:

MIX	C1	C2	C3	IC4	NC4	IC5	NC5	C6	C7	C8+	CO2	H2S	N2	He
1	95.48	2.57	0.70	0.20	0.08	0.04	0.03	0.05	0.03	0.05	0.20	0.0	0.54	0.03
2	90.98	2.90	1.02	0.21	0.17	0.10	0.15	0.07	0.04	0.02	0.0	0.0	4.25	0.09
3	94.49	1.51	0.69	0.12	0.14	0.02	0.07	0.03	0.19	0.0	0.05	0.0	2.70	0.0
4	91.82	2.81	1.28	0.32	0.32	0.09	0.08	0.05	0.02	0.01	0.32	0.0	2.84	0.04
5	95.73	1.01	0.43	0.06	0.10	0.01	0.03	0.0	0.05	0.0	0.07	0.0	2.51	0.0
6	93.76	0.92	0.18	0.02	0.03	0.0	0.01	0.0	0.0	0.0	0.10	0.0	4.98	0.0
7	97.97	0.14	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.97	0.0	0.89	0.0
8	97.15	0.28	0.01	0.01	0.01	0.01	0.01	0.01	0.0	0.0	0.08	0.0	2.35	0.08
9	95.82	0.42	0.29	0.11	0.13	0.01	0.06	0.01	0.04	0.04	1.07	0.05	1.88	0.07
10	96.15	1.52	0.11	0.05	0.09	0.0	0.04	0.01	0.0	0.0	0.10	0.0	1.84	0.09

	Pc 1	Tc 1	SG1/SG2	SM1/SM2	Pc 2	Tc 2	Pc 3	Tc 3	SG 3	SM 3
1	666.0391	352.4514	0.5862	16.9833	666.8730	352.8926	666.8994	353.1833	0.5823	16.8688
2	659.2444	350.9458	0.6088	17.6363	659.2444	350.9458	665.4939	356.4341	0.5929	17.1757
3	661.3308	348.4063	0.5912	17.1280	661.5732	348.5339	665.3909	351.7979	0.5803	16.8119
4	661.3301	353.7400	0.6092	17.6472	662.5828	354.4099	665.4983	357.4985	0.5957	17.2561
5	663.6284	345.0088	0.5784	16.7572	663.9607	345.1814	667.5156	348.0732	0.5677	16.4476
6	660.9434	340.2419	0.5824	16.8733	661.4050	340.4795	668.7454	346.1990	0.5613	16.2602
7	667.6260	342.8789	0.5678	16.4489	671.0886	344.6572	668.5798	343.7131	0.5548	16.0716
8	664.4480	341.1426	0.5663	16.4057	664.8271	341.3372	668.1558	343.9148	0.5559	16.1035
9	663.2122	344.6067	0.5843	16.9283	667.7385	346.9575	666.0686	346.8928	0.5663	16.4059
10	665.4507	345.1633	0.5734	16.6128	665.9089	345.4009	668.3428	347.4111	0.5651	16.3709

MIXTURES LISTED BELOW ARE FOR SOUR DRY GASES:

MIX	C1	C2	C3	IC4	NC4	IC5	NC5	C6	C7	C8+	CO2	H2S	N2	He
1	58.65	10.51	7.19	1.71	0.67	0.27	0.22	0.18	0.15	0.10	0.10	16.45	3.78	0.0
2	53.11	8.56	1.04	0.13	0.36	0.02	0.25	0.11	0.10	0.0	26.54	4.96	4.75	0.0
3	69.45	3.55	2.00	0.90	0.36	0.25	0.23	0.55	0.05	0.0	2.01	13.44	7.21	0.0
4	67.05	1.92	0.48	0.15	0.10	0.06	0.06	0.05	0.03	0.0	4.04	24.96	0.99	0.1
5	75.86	2.11	0.51	0.28	0.08	0.10	0.11	0.10	0.06	0.0	4.90	12.30	3.56	0.0
6	57.55	1.11	0.38	0.21	0.13	0.09	0.10	0.09	0.06	0.0	4.60	35.07	0.61	0.0
7	54.44	2.96	1.08	0.47	0.18	0.16	0.17	0.17	1.56	0.0	7.25	29.80	1.76	0.0
	Pc 1	Tc 1	SG1/SG2	SM1/SM2	Pc 2	Tc 2	Pc 3	Tc 3	SG 3	SM 3				
1	674.1328	429.9949	0.8494	24.6058	715.3210	453.0923	654.2178	418.3638	0.7754	22.4645				
2	731.1846	406.9126	0.9296	26.9314	781.7407	433.7813	667.5547	383.0879	0.6622	19.1850				
3	672.9080	386.3540	0.7656	22.1782	715.2844	408.1492	656.4150	375.4226	0.6558	18.9992				
4	730.4094	409.6035	0.7738	22.4160	794.4829	439.8667	666.2515	353.6658	0.5845	16.9336				
5	691.0029	376.4097	0.7208	20.8829	737.1531	399.1013	665.2637	355.1672	0.5897	17.0846				
6	765.3752	440.7095	0.8406	24.3522	836.8799	474.2458	663.8267	354.6150	0.5899	17.0905				
7	729.6140	446.2783	0.9066	26.2641	794.1934	478.9453	639.2095	383.7058	0.7010	20.3067				

MIXTURES LISTED BELOW ARE FOR SWEET WET GASES:

MIX	C1	C2	C3	IC4	NC4	IC5	NC5	C6	C7	C8+	CO2	H2S	N2	He
1	78.59	15.44	8.27	2.26	0.96	0.28	0.32	0.10	0.24	0.0	1.58	0.0	1.92	0.04
2	79.68	8.66	4.46	1.35	0.79	0.38	0.40	0.20	0.12	0.0	2.98	0.0	0.98	0.0
3	67.18	12.11	12.23	3.95	1.60	0.66	0.67	0.41	0.19	0.25	0.14	0.0	0.60	0.01
4	78.54	9.50	5.53	1.56	1.39	0.42	0.54	0.27	0.14	0.0	0.26	0.0	1.85	0.0
	Pc 1	Tc 1	SG1/SG2	SM1/SM2	Pc 2	Tc 2	Pc 3	Tc 3	SG 3	SM 3				
1	655.4868	418.4346	0.7994	23.1594	659.7375	421.1479	656.7429	422.9299	0.7843	22.7215				
2	659.4128	390.4717	0.7262	21.0390	667.2607	395.1187	657.9414	392.0916	0.6992	20.2551				
3	640.7180	441.8125	0.8649	25.0570	641.1838	442.1335	641.3040	443.2832	0.8634	25.0124				
4	652.0298	397.8206	0.7355	21.3082	652.9431	398.3777	654.2231	401.2141	0.7291	21.1213				

MIXTURES LISTED BELOW ARE FOR SOUR WET GASES:

MIX	C1	C2	C3	IC4	NC4	IC5	NC5	C6	C7	C8+	CO2	H2S	N2	He
1	63.41	7.88	5.31	2.53	0.79	0.66	0.49	0.52	0.22	0.10	0.61	9.69	7.70	0.09
2	55.03	17.48	10.11	3.78	1.27	0.34	0.55	0.60	0.27	0.10	0.48	7.65	2.33	0.01
3	49.44	12.60	8.38	4.15	1.23	1.01	0.77	0.75	0.35	0.15	0.33	8.82	12.00	0.02
4	51.05	12.43	11.63	2.58	1.19	0.23	0.36	0.12	0.15	0.0	11.40	3.10	5.74	0.02
5	36.60	6.65	7.74	4.44	1.84	1.12	1.20	0.63	0.33	0.0	2.40	35.73	1.32	0.00
6	53.88	9.82	8.98	3.64	1.49	0.79	0.86	0.40	0.24	0.02	2.19	13.26	4.40	0.03
7	44.26	16.12	9.55	2.94	2.71	0.24	0.36	0.52	0.39	0.15	17.54	3.46	1.75	0.01
8	51.09	11.02	7.20	2.04	0.88	0.25	0.31	0.09	0.10	0.0	5.18	18.02	3.80	0.02
9	43.19	13.61	10.44	4.16	2.48	0.61	0.87	0.27	0.27	0.0	3.00	19.70	1.37	0.03
	Pc 1	Tc 1	SG1/SG2	SM1/SM2	Pc 2	Tc 2	Pc 3	Tc 3	SG 3	SM 3				
1	649.5532	408.1501	0.8339	24.1572	679.0139	425.1724	645.4265	413.6025	0.7758	22.4753				
2	650.2253	452.1172	0.9145	26.4932	672.5876	466.6401	646.0520	454.8367	0.8875	25.7120				
3	633.5137	435.0137	0.9496	27.5086	658.3508	450.7991	635.0581	459.5972	0.9192	26.6281				
4	663.5459	435.1531	0.9530	27.6090	692.2656	453.4382	649.4316	447.6978	0.8624	24.9844				
5	700.3313	512.7036	1.0730	31.0835	756.5181	546.1555	621.1611	478.4258	0.9966	28.8723				
6	655.9189	447.0603	0.9338	27.0530	691.5144	468.8188	638.8530	446.2048	0.8759	25.3752				
7	673.2014	462.7322	1.0451	30.2753	706.8293	485.0994	640.3823	468.2903	0.9333	27.0378				
8	689.4319	443.7761	0.9130	26.4495	737.5474	470.7607	654.2166	428.1396	0.8022	23.2395				
9	670.0640	485.2344	1.0174	29.4739	713.3096	512.2737	636.6853	474.4138	0.9573	27.7319				

APPENDIX III

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C  THIS PROGRAM IS USED TO GENERATE VALUES FOR
C  -REDUCED COMPRESSIBILITY
C  -COMPRESSIBILITY FACTOR
C  -VISCOSITY
C  -PRODUCT OF COMPRESSIBILITY AND VISCOSITY
C  -PSEUDO GAS PRESSURE
C
C  RESULTS ARE ATTACHED
C
C  METHOD OF NUMERICAL INTERGRATION IS BY SIMPSON"S
C  1/3 RULE FOR EVEN STEP SIZES AND A COMBINATION OF
C  SIMPSON'S 1/3 & 3/8 RULE FOR ODD STEP SIZES.
C
C  VISCOSITY HAS BEEN CALCULATED USING D.DEAN & L.STIEL
C  MODEL. THE PAPER WAS PRESENTED IN AIChE JOURNAL,
C  MAY 1965.
C
C  Z FACTOR, REDUCED COMPRESSIBILITY AND DENSITY HAS
C  BEEN CALCULATED USING DRANCHUK, PURVIS, & ROBINSON
C  MODEL WHICH WAS PRESENTED IN THE TRAN OF AIME VOL.146,
C  PP140-149
C
C  SOUR GAS CORRECTION BY WICHERT & AZIZ CORRELATION
C
C
C  DOUBLE PRECISION NTC,NPC,SM,CG,XX
C  DOUBLE PRECISION XPROD,PROD,VG,VISC
C  DIMENSION P(20)
C
C  READ (8,10) G,PC,TC,T
10  FORMAT (F7.5,3(2X,F8.4))
   SM = G*28.75
C
C  READ (8,100) (P(IJ), IJ=1,19)
100 FORMAT (F5.1,1X,9(F6.1,1X),/,9(F6.1,1X))
   TR = T/TC
   L=2
   H=0.05
   WRITE (5,1) TR
   WRITE (5,50)
   WRITE (5,2)
   WRITE (5,3)
1  FORMAT ('1',/,2X,'The Value of Tr is = ',F5.2)
50 FORMAT (/,)
2  FORMAT (/,10X,'Pr',8X,'Pr/CrU',7X,'U',6X,'1/CrU',6X,
```



```

      + 'CrU', 7X, 'Visc', 7X, 'Cr', 7X, 'Pr/ZU', 6X,
      + '1/ZU', 8X, 'Dr')
3  FORMAT (4X, 106(' '), /)
C
      NTC=TC*5.0/9.0
      NPC=PC/14.7
      ZI=NTC**((1.0/6.0)/(SM**0.5*NPC**((2.0/3.0)))
      IF (TR-1.5) 5,6,6
5  VR=34.0E-05*TR**((8.0/9.0))
      GO TO 7
6  VR=166.8E-05*((0.1338*TR-0.0932)**((5.0/9.0)))
7  PR=0.2
C
      DO 4 I=1,19
      PX=P(I)
      PR=PX/PC
      N=((PR-0.195)/H)+2
      IF (N.LE.2) GO TO 33
      J=N-(N/2)*2
C
      IF (PR.GT.30.0) GO TO 4
      H=(PR-0.2)/N
      SUM=0.0
      XINTG=0.0
      PR1=0.2
C
      IF (J.EQ.0) GO TO 8
C
C      SIMPSON'S 3/8 RULE
C
      CALL ZKATZ (PR1,TR,DR,ITER,Z,CR)
      CALL VISC (ZI,VR,DR,V)
      SUM=PR1/(V*Z)
      DO 11 II=1,3
      PR1=PR1+H
      CALL ZKATZ (PR1,TR,DR,ITER,Z,CR)
      B=1.0
      IF (ITER.EQ.0) GO TO 24
      CALL VISC (ZI,VR,DR,V)
      IF (II.EQ.3) GO TO 9
      A=3.0
      GO TO 10
9  A=1.0
10 SUM =SUM + A*(PR1/(V*Z))
11 CONTINUE
      XINTG=3.0*H*SUM/8.0
      L=4
      N=N-1
      IF (N.LT.L) GO TO 34
      SUM=0.0
C

```



```

C   SIMPSON'S 1/3 RULE
C
8   CALL ZKATZ (PR1,TR,DR,ITER,Z,CR)
    B=2.0
    IF (ITER.EQ.0) GO TO 24
    CALL VISC (ZI,VR,DR,V)
    SUM = PR1/(Z*V)
    DO 12 KK=L,N
    PR1=PR1+H
    CALL ZKATZ (PR1,TR,DR,ITER,Z,CR)
    CALL VISC (ZI,VR,DR,V)
    M=KK-(KK/2)*2
    IF(M.EQ.0) GO TO 13
    A=2.0
    GO TO 14
13  A=4.0
14  SUM=SUM+A*(PR1/(Z*V))
12  CONTINUE
C
    PR1=PR1+H
    CALL ZKATZ (PR1,TR,DR,ITER,Z,CR)
    B=4.0
    IF (ITER.EQ.0) GO TO 24
    CALL VISC (ZI,VR,DR,V)
    SUM=SUM+PR1/(V*Z)
C
    XINTG=XINTG+H*SUM/3.0
C
    GO TO 34
33  XINTG=0.0
C
34  CALL ZKATZ (PR,TR,DR,ITER,Z,CR)
    B=5.0
    IF (ITER.EQ.0) GO TO 24
    CALL VISC (ZI,VR,DR,V)
    U=XINTG
    CRU = V*CR
    PRCRU=PR/CRU
    XCRU=1.0/CRU
    CG=CR/PC
    PRZU=PR/(Z*V)
    XZU=1/(Z*V)
    WRITE (5,15) PR,PRCRU,U,XCRU,CRU,V,CR,PRZU,XZU,DR,PX,
+ Z,CG
15  FORMAT (' ',2X,F10.2,2X,6F10.4,2X,4F10.4,2F10.7)
C
    GO TO 4
24  WRITE (7,25)
25  FORMAT (T1,' *** TR OR PR EXCEEDS MODEL LIMITS. ***')
    WRITE (7,26) PR,TR,B
26  FORMAT (2X,'PR=',F7.4,6X,'TR=',F6.4,6X,'B= ',F4.1)

```



```

GO TO 40
4  CONTINUE
32 CONTINUE
40  STOP
END
C
SUBROUTINE VISC (ZI,VR,DR,V)
C
VG=10.8E-05*(EXP(1.439*DR)-EXP(-1.11*DR**1.858))
V=(VR+VG)/ZI
RETURN
END
C
C
SUBROUTINE ZKATZ(PR,TR,DR1,ITER,Z,CR)
C
DIMENSION A(8)
DATA A/0.31506237,-1.0467099,-0.57832729,0.53530771,
*      -0.6123032,-0.10488813,0.68157001,0.68446549/
ITER=0
DR=1.0
IF(TR-1.05)10,1,1
1  IF(TR-3.0)2,2,10
2  IF(PR-30.0)3,3,10
3  DO 8 ITER=1,10
    DR2=DR**2
    T1=(A(1)*TR+A(2)+A(3)/TR**2)*DR
    T2=(A(4)*TR+A(5))*DR2
    T3=A(5)*A(6)*DR**5
    T4=A(7)*DR2/TR**2
    T5=A(8)*DR2
    T6=EXP(-T5)
    P=(TR+T1+T2+T3)*DR+T4*DR*(1.0+T5)*T6
    DP=TR+2.0*T1+3.0*T2+6.0*T3+T4*T6*(3.0+3.0*T5
+   -2.0*T5**2)
    DR1=DR-(P-0.270*PR)/DP
    IF(DR1)4,4,5
4  DR1=0.5*DR
5  IF(DR1-2.2)7,7,6
6  DR1=DR+0.9*(2.2-DR)
7  IF(ABS(DR-DR1)-0.1E-04)9,8,8
8  DR=DR1
9  Z=0.270*PR/(DR1*TR)
    DZ = (T1+2.0*T2+5.0*T3+2.0*T4*(1.0+T5
+   -T5**2.0)*T6)/(TR*DR1)
    CR = 1.0/PR -0.270*DZ/(Z**2*TR*(1.0 + DR1*DZ/Z))
10 RETURN
END

```


APPENDIX IV

C THIS PROGRAM IS USE TO DETERMINE VISCOSITY
C BY DEAN AND STIEL MODEL, CARR, KOBAYASHI
C AND BURROWS, AND LEE GONZALEZ AND AND EAKIN;
C
C REDUCED DENSITY IS SUPPLIED BY
C DRANCHUK, PURVIS, AND ROBERTSON'S
C MODEL OF THE BWR SOLUTION.
C
C THIS PROGRAM ELIMINATED ALL EFFECTS OF CO₂ ,H₂S AND N₂,
C FROM THE GAS COMPOSITION.
C METHOD A INCLUDES ALL CORRECTION FACTORS,
C METHOD B EXCLUDES THESE CORRECTION FACTORS,
C AND METHOD C PROVIDES ANALYSIS ON ACID GAS FREE BASES.
C
C CARR, KOBAYASHI AND BURROWS CORRELATION AND LAGRANGE
C INTERPOLATION WERE PROVIDED BY THE ERCB IN G-3
C APPENDIX 'D', 3 RD EDITIONS
C
C RESULTS OF THIS PROGRAM IS ATTACHED
C
C NOMENCLATURE USED WITHIN THIS PROGRAM
C
C A - MOLAR FRACTION OF H₂S + CO₂
C B - MOLAR FRACTION OF H₂S
C DE - GAS DENSITIES
C DIFF- DIFFERENCE BETWEEN THE VARIOUS METHODS
C E3 - WICHERT & AZIZ CORRECTION FOR ACID GASES
C G - GAS GRAVITY (ENTER 0.0 IN DATA READ STATEMENT
C TO CALCULATED G FROM COMPOSITION)
C NN - NUMBER OF MIXTURES
C NP - CRITICAL PRESSURE ATM
C NT - CRITICAL TEMPERATURE K
C P - EVALUATION PRESSURE PSIA
C PPC - CRITICAL PRERRURE PSIA
C PR - REDUCED PRESSURE
C R - UNIVERSAL GAS CONSTANT
C 10.732 PSIA-CU-FT/DEG-R-LBMOL
C SM - PSEUDO MOLECULAR WEIGHT LB/LBMOL
C TC - CRITICAL TEMPERATURE DEG R
C TCO - OLD CRITICAL TEMPERATURE FOR USE IN WICHERT &
C AZIZ CORRELATION
C TR - REDUCED TEMPERATURE
C VC - CRITICAL VOLUME CU-FT/LBMOL
C V1 - GAS VISCOSITY AS CALCULATED BY DEAN & STIEL
C METHOD; cp
C V2 - GAS VISCOSITY AS CALCULATED BY CARR, KOBAYASHI


```

C      & BURROWS; cp
C      V3 - GAS VISCOSITY AS CALCULATED BY LEE, GONZALES,
C      & EAKIN; cp
C      VISR- VISCOSITY RATIO FROM CARR, KOBAYASHI & BURROWS
C      MODEL
C      VG - VISCOSITY FACTOR LESS THE VISCOSITY EFFECTS AT
C      MODERATE PRESSURE (0.2-5 ATM)
C      VR - RESIDUAL VISCOSITY
C      WM - MOLECULAR WEIGHT LB/LBMOL
C      X(1)-X(14)-MOLAR % OF GAS COMPOSITION IN THE ORDER OF
C      C1,C2,C3,IC4,NC4,IC5,NC5,C6,C7,C8,CO2,H2S,N2,HE
C      XK, - CONSTANTS FOR LEE, GONZALEZ AND EAKIN
C      XX, VISCOSITY CORRELATION
C      XY.
C      XT - SANDFACE TEMPERATURE DEG R
C      ZC - CRITICAL COMPRESSIBILITY FACTOR
C      ZI - VISCOSITY PARAMETER
C      ZP - PRESSURE, PSIA
C
C      PROPERTIES LISTED BELOW HAVE BEEN OBTAINED FROM
C      GAS PROCESSOR SUPPLIERS ASSOCIATION, ENGINEERING
C      DATA BOOK, NINTH EDITION
C
C      CONVERSION USED TO OBTAINED UNITS USED IN THE PROGRAM
C      ARE:
C      TC = TC(OF) + 460.0
C      VC = VC(FT3/LB)*WM(LB/LBMOL)
C      ZC = PC*VC/R*TC
C
C      GAS COMPOSITION IF KNOWN, SHOULD BE EXPRESSED IN
C      PERCENTAGES AND ENTERED IN THE FOLLOWING ORDER
C
C      C1, C2, C3, nC4, iC4, nC5, iC5, C6, C7
C      C8+, CO2, H2S, N2, He
C
C      CRITICAL PROPERTIES HAVE BEEN DETERMINED BY KAY'S RULE
C      EXCEPT FOR CRITICAL PRESSURE WHICH HAS BEEN
C      DETERMINED BY PRAUSNITZ AND GUNN MIXING RULE.
C
C      -----
C
C      DIMENSION ZPC(5),ZTC(5),ZERR(5),ZF(5),ZT(5),TT(5)
C      DIMENSION XP(5),X(14),TP(5),ZP(6),F(6)
C      DOUBLE PRECISION ZX1,ZX2,ZX3,VC,SM,SVC,TT,XP,V1,V2,Z
C      DOUBLE PRECISION G1,G2
C
C      READ (5,5) SSA,NN
5      FORMAT (F6.3,1X,I2)
C      TR=1.05
C      R=10.732

```



```

WRITE (6,10) TR
WRITE (7,11) TR
10  FORMAT (2X,'THE FOLLOWING CALCULATIONS ARE FOR A ',
+ 'REDUCED TEMPERATURE OF ',F4.2,/)
11  FORMAT (2X,'THE FOLLOWING CALCULATIONS ARE FOR A ',
+ 'REDUCED TEMPERATURE OF ',F4.2,/)
C
DO 240 I=1,NN
20  READ (5,30) (X(IJ), IJ=1,14)
30  FORMAT (14(F5.2,1X))
C
CALL MIXT(X(1),X(2),X(3),X(4),X(5),X(6),X(7),X(8)
+,X(9),X(10),X(11),X(12),X(13),X(14),ZPC(1),ZTC(1),
+H2S1,CO21,XN21,ZPC(2),ZTC(2),H2S2,CO22,XN22,
+ZPC(3),ZTC(3),XG1,XG2,SM1,SM2)
C
C CHECKING UPPER AND LOWER BOUNDARY AS FOLLOWS
C
DO 35 IA=1,3
ZERR(IA)=0.0
TR=1.05
CALL BOUND (TR,ZTC(IA),XG1,XG2,ZERR(IA),ZT(IA))
35  CONTINUE
C
PR=0.25
C
C-----
C CONSTANT FACTOR DETERMINATION FOR DEAN AND STIEL
C NATURAL GAS VISCOSITY CORRELATION
C
IF(TR-1.5) 80,90,90
80  VR=34.0E-05*TR**(8.0/9.0)
GO TO 100
90  VR=166.8E-05*(0.1338*TR-0.0932)**(5.0/9.0)
100 DO 105 IC=1,3
TT(IC)=ZTC(IC)*5.0/9.0
XP(IC)=ZPC(IC)/14.7
105 CONTINUE
Z1=TT(1)**(1.0/6.0)/(SM1**0.5*XP(1)**(2.0/3.0))
Z2=TT(2)**(1.0/6.0)/(SM1**0.5*XP(2)**(2.0/3.0))
Z3=TT(3)**(1.0/6.0)/(SM2**0.5*XP(3)**(2.0/3.0))
C
C-----
C CONSTANT FACTORS DETERMINATION FOR LEE GONZALEZ AND
EAKIN
C NATURAL GAS VISCOSITY COORELATION AS PRESENTED IN SPE AUG
C 1966.
C
XT1 = TR*ZTC(1)
XK1 = ((9.4 + 0.02*SM1)*XT1**1.5)/(209.0 +
+ 19.0*SM1+XT1)

```


XX1 = 3.5 + 986.0/XT1 + 0.01*SM1
 XY1 = 2.4 - 0.2*XX1

C

XT2 = TR*ZTC(2)
 XK2 = ((9.4 + 0.02*SM1)*XT2**1.5)/(209.0 +
 + 19.0*SM1+XT2)
 XX2 = 3.5 + 986.0/XT2 + 0.01*SM1
 XY2 = 2.4 - 0.2*XX2

C

XT3 = TR*ZTC(3)
 XK3 = ((9.4 + 0.02*SM2)*XT3**1.5)/(209.0 +
 + 19.0*SM2+XT3)
 XX3 = 3.5 + 986.0/XT3 + 0.01*SM2
 XY3 = 2.4 - 0.2*XX3

DO 205 IB=1,50

IF (PR .LT. 0.01) GO TO 160

IF (PR .GT. 20.0) GO TO 220

C

XP1 = PR*ZPC(1)
 XP2 = PR*ZPC(2)
 XP3 = PR*ZPC(3)
 XT1 = TR*ZTC(1)
 XT2 = TR*ZTC(2)
 XT3 = TR*ZTC(3)
 CALL ZKATZ (PR,TR,ZZ,DR,ITER)
 DE1 = XP1*SM1/(R*62.4*XT1*ZZ)
 DE2 = XP2*SM1/(R*62.4*XT2*ZZ)
 DE3 = XP3*SM1/(R*62.4*XT3*ZZ)
 CALL VIS3 (XK1,XX1,XY1,DE1,V3A)
 CALL VIS3 (XK2,XX2,XY2,DE2,V3B)
 CALL VIS3 (XK3,XX3,XY3,DE3,V3C)
 CALL VIS2 (PR,TR,XG1,ZT(1),H2S1,CO21,XN21,V1A)
 CALL VIS2 (PR,TR,XG1,ZT(2),H2S2,CO22,XN22,V1B)
 CALL VIS2 (PR,TR,XG2,ZT(3),H2S2,CO22,XN22,V1C)
 CALL VIS1 (Z1,VR,DR,V2A)
 CALL VIS1 (Z2,VR,DR,V2B)
 CALL VIS1 (Z3,VR,DR,V2C)

C

DIFF1 = (V1A-V1B)*100.0/V1A
 DIFF1A= (V1A-V1C)*100.0/V1A
 DIFF2 = (V1A-V2A)*100.0/V1A
 DIFF2A= (V2A-V2B)*100.0/V2A
 DIFF2B= (V2A-V2C)*100.0/V2A
 DIFF3 = (V1A-V3A)*100.0/V1A
 DIFF3A= (V2A-V3A)*100.0/V2A
 DIFF3B= (V3A-V3B)*100.0/V3A
 DIFF3C= (V1B-V3B)*100.0/V1B
 DIFF3D= (V2B-V3B)*100.0/V2B
 DIFF3E= (V3A-V3C)*100.0/V3A
 DIFF3F= (V3B-V3C)*100.0/V3B


```

    DIFF3G= (V1C-V3C)*100.0/V1C
    DIFF3H= (V2C-V3C)*100.0/V2C
C
    DO 140 IC=1,3
        ZP(IC) = PR*ZPC(IC)
140  CONTINUE
C
    WRITE(6,155) I,PR,ZP(1),ZP(2),ZP(3),V1A,V1B,V1C,
+V2A,V2B,V2C,V3A,V3B,V3C
    CALL ZKATZ (PR,TR,ZZ,DR,ITER)
C
    WRITE(7,156) I,PR,DIFF1,DIFF1A,DIFF2,DIFF2A,DIFF2B
+DIFF3,DIFF3A,DIFF3B,DIFF3C,DIFF3D,DIFF3E,DIFF3F,
+DIFF3G,DIFF3H
155  FORMAT(I2,2X,F5.2,2X,17(F10.4,2X))
156  FORMAT(I2,2X,F5.2,2X,17(F8.4,2X))
C
    IF (PR-0.29)160,165,165
160  PR=PR+0.05
    GO TO 205
165  IF (PR-1.49) 170,175,175
170  PR=PR+0.10
    H=0.02
    GO TO 205
175  IF (PR-2.99) 180,185,185
180  PR=PR+0.50
    H=0.1
    GO TO 205
185  IF (PR-9.99) 190,195,195
190  PR=PR+1.0
    H=0.20
    GO TO 205
195  IF(PR-19.999) 200,240,240
200  PR=PR+5.0
    H=0.5
205  CONTINUE
220  WRITE (6,212)
    WRITE (7,212)
212  FORMAT (' ',/)
240  CONTINUE
C
    WRITE (6,211) ZTC(1),ZTC(2),ZTC(3),ZPC(1),ZPC(2),
+ZPC(3)
    WRITE (7,210) XT1
210  FORMAT (//,'TEMPERATURE IS OUTSIDE RANGE OF CKB',
+ ' MODEL WHERE TEMP>860:','/, 'IT IS ASSUMED THAT
+ VISCOSITY',' CORRELATION BY CKB WILL
+ APPLY','/, 'WITHIN ACCEPTABLE',
+ ' ENGINEERING LIMITS WHEN THESE TEMPERATURES','/,
+ 'EXCEED THE MODELS RANGE. '//, 'MIXTURE TEMPERATURE IS
+ ',F7.2,' DEG R',/)

```



```
211  FORMAT (//,6(F10.4,2X))
      GO TO 260
```

```
  C
250  WRITE(7,255) PR,TR,XG1,XG2,T,Z,M
255  FORMAT ('ERROR WAS DETECTED', 6G12.4)
260  STOP
      END
```

```
  C-----
  C
```

```
      SUBROUTINE MIXT(X1,X2,X3,X4,X5,X6,X7,X8,X9,X10,
+X11,X12,X13,X14,PC1,TC1,H2S1,CO21,XN21,PC2,TC2,
+H2S2,CO22,XN22,PC3,TC3,G1,G2,SM1,SM2)
```

```
  C
      DIMENSION TC(14), VC(14), WM(14), ZC(14), ZX(14)
```

```
  C
      ZX(1)=X1
      ZX(2)=X2
      ZX(3)=X3
      ZX(4)=X4
      ZX(5)=X5
      ZX(6)=X6
      ZX(7)=X7
      ZX(8)=X8
      ZX(9)=X9
      ZX(10)=X10
      ZX(11)=X11
      ZX(12)=X12
      ZX(13)=X13
      ZX(14)=X14
```

```
  C
      DATA TC /343.32, 550.10, 666.01, 765.62, 734.96,
+      845.60, 829.03, 913.60, 972.70, 1024.1,
+      547.87, 672.60, 227.30, 9.69/
```

```
  C
      DATA VC /1.5851, 2.3695, 3.2500, 4.0861, 4.2082,
+      4.8630, 4.8991, 5.9204, 6.9142, 7.8820,
+      1.5051, 1.5675, 1.4455, 0.9207/
```

```
  C
      DATA WM /16.043, 30.070, 44.097, 58.124, 58.124,
+      72.151, 72.151, 86.178, 100.205, 114.232,
+      44.010, 34.076, 28.013, 4.003/
```

```
  C
      DATA ZC /0.2876, 0.2844, 0.2805, 0.2742, 0.2826,
+      0.2621, 0.2703, 0.2641, 0.2631, 0.2589,
+      0.2745, 0.2252, 0.2925, 0.2923/
```

```
  C
      PTC = 0.0
      SZC = 0.0
      SVC = 0.0
      SM1 = 0.0
```



```

C
DO 40 II=1,14
PTC = PTC + ZX(II) * TC(II)/100.0
SZC = SZC + ZX(II) * ZC(II)/100.0
SVC = SVC + ZX(II) * VC(II)/100.0
SM1 = SM1 + ZX(II) * WM(II)/100.0
40  CONTINUE
C
CO21 = ZX(11)
H2S1 = ZX(12)
XN21 = ZX(13)
C
G1=SM1/28.97
R=10.732
PPC = R*PTC*SZC/SVC
TC2=PTC
PC2=PPC
C
IF (CO21 .EQ. 0.0 .AND. H2S1 .EQ. 0.0) GO TO 51
C
CALL WACOR (H2S1,CO21,PPC,PTC,PC1,TC1)
GO TO 52
C
51  TC1=PTC
PC1=PPC
52  TC3 = 0.0
SZC = 0.0
SVC = 0.0
SM2 = 0.0
C
DM=100.0-ZX(11)-ZX(12)-ZX(13)
ZX(11)=0.0
ZX(12)=0.0
ZX(13)=0.0
C
DO 53 II=1,14
TC3 = TC3 + ZX(II) * TC(II)/DM
SZC = SZC + ZX(II) * ZC(II)/DM
SVC = SVC + ZX(II) * VC(II)/DM
SM2 = SM2 + ZX(II) * WM(II)/DM
53  CONTINUE
C
CO22 = 0.0
H2S2 = 0.0
XN22 = 0.0
C
G2=SM2/28.97
R=10.732
PC3 = R*TC3*SZC/SVC
C
RETURN

```


END

C-----
C
C CORRECTION FOR H2S AND CO2 CONTAMINATION
C BY WICHERT AND AZIZ CORRELATION
C

SUBROUTINE WACOR (H2S,CO2,PPC,PTC,PC,TC)

C
A=(CO2+H2S)/100.0
B=H2S/100.0
E3=120.0*(A**0.9-A**1.6)+15.0*(B**0.5-B**4.0)
TC=PTC-E3
PC=PPC*TC/(PTC+(B*(1-B)*E3))
RETURN
END

C-----
C
C SUBROUTINE BOUND (TR,TC,G1,G2,ERR,T)

C T=TR*TC

C CHECKING UPPER AND LOWER BOUNDARY AS FOLLOWS

C TR - 1.05 TO 3.00

C G - 0.55 TO 1.50

C T - 500.0 TO 860.0 DEG R

C IF OUTSIDE OF THESE RANGES THEN GO TO PROGRAM'S END

C IF (TR .LT. 1.05 .OR. TR .GT. 3.00) ERR=1.0

C IF (G1 .LT. 0.55 .OR. G1 .GT. 1.50) ERR=21.0

C IF (G2 .LT. 0.55 .OR. G2 .GT. 1.50) ERR=22.0

C IF (T .LT. 500.0 .OR. T .GT. 860.0) ERR=3.0

C RETURN

C END

C-----
C
C NATURAL GAS VISCOSITY DETERMINATION USING DEAN AND STIEL
C CORRELATION AS PRESENTED IN AIChE MAY 1965.
C

SUBROUTINE VIS1 (ZI,VR,DR,V1)

C VG = 10.8E-05*(EXP(1.439*DR)-EXP(-1.11*DR**1.858))

C V1 = 10000.0*(VG+VR)/ZI

C RETURN

C END

C-----


```

C
C NATURAL GAS VISCOSITY DETERMINATION USING CARR
C KOBAYASHI AND BURROWS CORRELATION AND LAGRANGE
C INTERPOLATION
C
C SUBROUTINE VIS2 (PR,TR,G,T,H2S,CO2,XN2,V2)
C
C DIMENSION TRBL(13), PRBL(22),VBL(22,13), VB1(22,5),
+ VB1A(22,2), VB2(22,6)
C
C EQUIVALENCE (VB1(1,1),VBL(1,1)),(VB1A(1,1), VBL(1,6)),
+ (VB2(1,1), VBL(1,8))
C
C DATA TRBL /
+ 1.05, 1.10, 1.15, 1.20, 1.30, 1.40, 1.50,
+ 1.60, 1.75, 2.00, 2.25, 2.50, 3.00/
C
C DATA PRBL /
+ 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.2
+, 1.4, 1.6, 1.8, 2.0, 3.0, 4.0, 6.0, 8.0, 10.0, 15.0,
+ 20.0/
C
C DATA VB1 /
+1.000,1.012,1.025,1.050,1.075,1.100,1.145,1.195,1.285,
+1.415,1.760,2.285,2.865,3.290,3.650,4.760,5.500,6.460,
+7.150,7.680,8.650,9.370,
+1.000,1.011,1.023,1.043,1.065,1.086,1.120,1.150,1.195,
+1.255,1.435,1.700,2.070,2.465,2.800,3.850,4.655,5.720,
+6.500,7.060,8.100,8.880,
+1.000,1.010,1.021,1.036,1.055,1.073,1.095,1.120,1.145,
+1.175,1.280,1.420,1.590,1.850,2.160,3.225,3.975,5.030,
+5.820,6.385,7.410,8.180,
+1.000,1.009,1.019,1.030,1.045,1.060,1.070,1.085,1.110,
+1.135,1.195,1.285,1.425,1.570,1.750,2.600,3.350,4.380,
+5.125,5.740,6.750,7.500,
+1.000,1.008,1.017,1.027,1.040,1.054,1.063,1.075,1.100,
+1.120,1.155,1.215,1.285,1.360,1.460,2.020,2.560,3.500,
+4.185,4.755,5.790,6.500/
C
C DATA VB1A /
+1.000,1.007,1.015,1.024,1.035,1.048,1.056,1.067,1.089,
+1.100,1.135,1.185,1.235,1.280,1.335,1.690,2.110,2.790,
+3.380,3.860,4.790,5.410,
+1.000,1.006,1.013,1.021,1.030,1.042,1.049,1.059,1.076,
+1.100,1.120,1.150,1.185,1.220,1.260,1.500,1.785,2.325,
+2.820,3.230,4.060,4.610/
C
C DATA VB2 /
+1.000,1.005,1.011,1.018,1.025,1.036,1.042,1.051,1.067,
+1.070,1.095,1.120,1.150,1.180,1.215,1.385,1.595,2.030,
+2.425,2.770,3.490,4.025,

```


+1.000,1.004,1.009,1.015,1.021,1.030,1.035,1.043,1.056,
+1.065,1.090,1.110,1.125,1.145,1.165,1.280,1.435,1.770,
+2.095,2.375,2.990,3.500,
+1.000,1.003,1.007,1.012,1.017,1.024,1.028,1.035,1.045,
+1.055,1.060,1.070,1.080,1.095,1.110,1.205,1.290,1.500,
+1.725,1.955,2.480,2.925,
+1.000,1.002,1.005,1.009,1.013,1.018,1.021,1.027,1.034,
+1.040,1.045,1.055,1.065,1.075,1.085,1.145,1.210,1.340,
+1.485,1.665,2.085,2.460,
+1.000,1.001,1.003,1.006,1.009,1.012,1.015,1.019,1.023,
+1.025,1.030,1.040,1.050,1.060,1.065,1.105,1.155,1.245,
+1.360,1.485,1.830,2.150,
+1.000,1.000,1.001,1.003,1.005,1.007,1.009,1.011,1.013,
+1.015,1.020,1.025,1.030,1.035,1.040,1.060,1.085,1.140,
+1.205,1.265,1.495,1.750/

C

C

C INITIALIZING UPPER AND LOWER BOUNDARIES FOR THE
C LOOK-UP TABLES

C

LOPR = 2

LOTR = 3

IHIPR = 21

IHITR = 11

IERR = 0

C

C LOCATE TR IN INDEX

C

DO 100 J = LOTR,IHITR

IF (TRBL(J) .GE. TR) GO TO 120

100 CONTINUE

J = IHITR+1

C

C CHECK PR AGAINST INDEX

C

C IF PR<0.01; PROFORM LAGRANGE INTERPOLATION
C USING RATIO FOR PR=0.01

C

C IF PR>20.0; PROFORM LAGRANGE INTERPOLATION
C USING RATIO FOR PR=20.0

C

C OTHERWISE LOCATE PR

C

120 IF (PRBL(LOPR-1) .LT. PR) GO TO 160

I = 1

ICALL = 1

GO TO 320

140 VISR = 1.0+(PR*(VISI-1.0))

GO TO 300

160 IF (PRBL(IHIPR+1) .GT. PR) GO TO 200

I = IHIPR+1


```

        ICALL = 2
        GO TO 320
180  VISR = VISI
        GO TO 300
200  DO 220 I = LOPR,IHIPR
        IF (PRBL(I) .GE. PR) GO TO 240
220  CONTINUE
        I = IHIPR+1
240  ICALL = 3
        GO TO 320
260  VISJ = VISI
        I = I-1
        ICALL = 4
        GO TO 320
280  I = I+1
        VISR = VISI+((PR-PRBL(I-1))/(PRBL(I)-PRBL(I-1)))*
+      (VISJ-VISI)
C
C  CORRECTION FOR H2S, CO2, AND N2
C
300  NT = T-460.0
        VISU = 0.126585E-01-0.611823E-02*G+0.164574E-02*G**2.0
+      +0.164574E-04*NT-0.719221E-06*G*NT-0.609046E-06*
+      G**2.0*NT
        CORH2S = (0.113E-03*H2S*G-0.38E-04*H2S+0.10E-05)*
+      (1.0/(1.0+G))+0.10E-05
        CORCO2 = (0.134E-03*CO2*G-0.40E-05*CO2+0.40E-05*G)*
+      (1.0/(1.0+G))-0.30E-05
        CORN2 = (0.170E-03*XN2*G+0.21E-04*XN2+0.10E-04*G)*
+      (1.0/(1.0+G))-0.60E-05
        VISA = VISU+CORH2S+CORCO2+CORN2
        V2 = 10000.0*VISR*VISA
C
        GO TO 360
C
C  CALL LAGRANGE INTERPOLATION
C
320  CALL XLGR4(TR,TRBL(J-2),TRBL(J-1),TRBL(J),TRBL(J+1),
+      VISI,VBL(I,J-2),VBL(I,J-1),VBL(I,J),VBL(I,J+1))
        GO TO (140,180,260,280), ICALL
340  IERR = 1
        VISR = 0.0
        V2 = 0.0
360  RETURN
        END

C-----
C
C  SUBROUTINE XLGR4(X,X1,X2,X3,X4,Y,Y1,Y2,Y3,Y4)
C
C  A1 = X1-X2

```



```

A2 = X1-X3
A3 = X1-X4
A4 = X2-X3
A5 = X2-X4
A6 = X3-X4
B1 = X-X1
B2 = X-X2
B3 = X-X3
B4 = X-X4
Y = B2/A1*B3/A2*B4/A3*Y1-B1/A1*B3/A4*B4/A5*Y2+
+ B1/A2*B2/A4*B4/A6*Y3-B1/A3*B2/A5*B3/A6*Y4
RETURN
END

```

```

C-----
C
C NATURAL GAS VISCOSITY DETERMINATION USING LEE GONZALEZ
C AND EAKIN CORRELATION AS PRESENTED IN SPE AUG 1966
C
C SUBROUTINE VIS3 (XK,XX,XY,DE,V3)
C
C V3 = XK*EXP(XX*DE**XY)
C RETURN
C END

```

```

C-----
C
C SUBROUTINE ZKATZ(PR,TR,Z,DR,ITER)
C
C DIMENSION A(8)
C DATA A/0.31506237,-1.0467099,-0.57832729,0.53530771,
+ -0.6123032,-0.10488813,0.68157001,0.68446549/
C ITER = 0
C DR = 1.0
C IF(TR-1.05)100,10,10
10 IF(TR-3.0)20,20,100
20 IF(PR-30.0)30,30,100
30 DO 80 ITER = 1,10
C DR2 = DR**2
C T1 = (A(1)*TR+A(2)+A(3)/TR**2)*DR
C T2 = (A(4)*TR+A(5))*DR2
C T3 = A(5)*A(6)*DR**5
C T4 = A(7)*DR2/TR**2
C T5 = A(8)*DR2
C T6 = EXP(-T5)
C P = (TR+T1+T2+T3)*DR+T4*DR*(1.0+T5)*T6
C DP = TR+2.0*T1+3.0*T2+6.0*T3+T4*T6*(3.0+3.0*
+ T5-2.0*T5**2)
C DR1 = DR-(P-0.270*PR)/DP
C IF(DR1)40,40,50
40 DR1 = 0.5*DR
50 IF(DR1-2.2)70,70,60

```



```

60 DR1 = DR+0.9*(2.2-DR)
70 IF(ABS(DR-DR1)-0.1E-04)90,80,80
80 DR = DR1
90 Z = 0.270*PR/(DR1*TR)
   DR = 0.270*PR/(Z*TR)
   DZ = A(1)+A(2)/TR+A(3)/TR**3 + 2.0*(A(4)+A(5)/TR)*DR +
+   5.0*A(5)*A(6)*DR**4/TR + (1.0+A(8)*DR**2-
+   A(8)**2**DR**4)*2.0*A(7)*DR/TR**3*EXP(-A(8)*
+   DR**2)
   CR = 1.0/PR -0.270*DZ/(Z**2*TR*(1.0 + DR/Z*DZ))
100 RETURN
   END

```


APPENDIX V

C THIS PROGRAM IS USE TO DETERMINE THE PSEUDO GAS
C PRESSURE INTERGRAL USING THE TRAPIZODIAL RULE.
C COMPRESSILITY FACTOR WAS OBTAINED
C USING DRANCHUK, PURVIS, AND ROBERTSON'S
C MODEL OF THE BWR SOLUTION, AND VISCOSITY
C BY DEAN AND STIEL MODEL, AND CARR, KOBAYASHI
C AND BURROWS
C
C CARR, KOBAYASHI AND BURROWS CORRELATION AND LAGRANGE
C INTERPOLATION WERE PROVIDED BY THE ERCB IN THEIR
C APPENDIX 'D', PROGRAMS
C
C A COMPARISON OF THE EFFECTS OF CO₂, H₂S AND N₂ WERE ALSO
C MADE BETWEEN THE METHODS WITH THE RESULTS STORED IN
C FILES 6-10.
C
C A LISTING OF THESE RESULTS HAVE BEEN ATTACHED
C
C NOMENCLATURE USED WITHIN THIS PROGRAM
C
C A - MOLAR FRACTION OF H₂S + CO₂
C B - MOLAR FRACTION OF H₂S
C DIFF1-DIFFERENCE IN % BETWEEN OTHER XINTG AND XINTG2
C DIFF2-DIFFERENCE IN % BETWEEN OTHER XINTG AND XINTG3
C DIFF3-DIFFERENCE IN % BETWEEN OTHER XINTG AND XINTG4
C DIFF4-DIFFERENCE IN % BETWEEN OTHER XINTG AND XINTG5
C DIFF5-DIFFERENCE IN % BETWEEN OTHER XINTG AND XINTG6
C E3 - WICHERT & AZIZ CORRECTION FOR ACID GASES
C G - GAS GRAVITY (ENTER 0.0 IN DATA READ STATEMENT
C TO CALCULATED G FROM COMPOSITION)
C H - STEP SIZE INTERVAL
C XINTG1 - PSEUDO PRESSURE CALCULATED USING CKB'S
C VISCOSITY AND WA CORRELATION TO CORRECT FOR
C ACID GASES
C XINTG2 - PSEUDO PRESSURE CALCULATED USING DS'S
C VISCOSITY AND WA CORRELATION TO CORRECT FOR
C ACID GASES
C XINTG3 - PSEUDO PRESSURE CALCULATED USING CKB'S
C VISCOSITY W/O WA CORRELATION TO CORRECT FOR
C ACID GASES, HOWEVER H₂S AND CO₂ WERE
C INCLUDED IN DETERMINING CRITICAL PROPERTIES
C XINTG4 - PSEUDO PRESSURE CALCULATED USING CKB'S
C VISCOSITY W/O ANY H₂S OR CO₂ EFFECTS.
C XINTG5 - PSEUDO PRESSURE CALCULATED USING DS'S
C VISCOSITY W/O WA CORRELATION TO CORRECT FOR
C ACID GASES, HOWEVER H₂S AND CO₂ WERE

INCLUDED IN DETERMINING CRITICAL PROPERTIES
 XINTG6 - PSEUDO PRESSURE CALCULATED USING DS'S
 VISCOSITY W/O ANY H₂S OR CO₂ EFFECTS.
 N - NUMBER OF INTERVAL STEPS
 NN - NUMBER OF PSEUDO-PRESSURE TO CALCULATE
 NP - CRITICAL PRESSURE ATM
 NT - CRITICAL TEMPERATURE K
 PPC - CRITICAL PRERRURE PSIA
 PR - REDUCED PRESSURE
 PX1:4- PRESSURE STEP IN THE TRAPIZODIAL INTEGRAL
 Q - FLOW RATES MMSCF/D
 R - UNIVERSAL GAS CONSTANT
 10.732 PSIA-CU-FT/DEG-R-LBMOL
 S1 - SWITCH-ELIMINATING CO₂,H₂S&N₂ FROM GAS
 COMPOSITION
 S2 - SWITCH-ELIMINATES CO₂,H₂S,N₂ FROM CKB MODEL
 S3 - SWITCH-ELIMATES CO₂&H₂S FROM WA CORRECTION
 SM - PSEUDO MOLECULAR WEIGHT LB/LBMOL
 T - SANDFACE TEMPERATURE DEG R
 TC - CRITICAL TEMPERATURE DEG R
 TCO - OLD CRITICAL TEMPERATURE FOR USE IN WICHERT &
 AZIZ CORRELATION
 TI - TIME hrs
 TP - PREVIOUS PRODUCING TIME
 TR - REDUCED TEMPERATURE
 TT - CRITICAL TEMP DEG R
 VC - CRITICAL VOLUME CU-FT/LBMOL
 V - GAS VISCOSITY AS CALCULATED BY DEAN & STIEL
 METHOD; cp
 VIS2- GAS VISCOSITY AS CALCULATED BY CARR, KOBAYASHI
 & BURROWS; cp
 VISR- VISCOSITY RATIO FROM CARR, KOBAYASHI & BURROWS
 MODEL
 VG - VISCOSITY FACTOR LESS THE VISCOSITY EFFECTS AT
 MODERATE PRESSURE (0.2-5 ATM)
 VR - RESIDUAL VISCOSITY
 WM - MOLECULAR WEIGHT LB/LBMOL
 XP - CRITICAL PRESSURE ATM
 XT - HORNER'S TIME RATIO
 ZC - CRITICAL COMPRESSIBILITY FACTOR
 ZI - VISCOSITY PARAMETER
 PROPERTIES LISTED BELOW HAVE BEEN OBTAINED FROM
 GAS PROCESSOR SUPPLIERS ASSOCIATION, ENGINEERING
 DATA BOOK, NINTH EDITION
 CONVERSION USED TO OBTAINED UNITS USED IN THE PROGRAM
 ARE:

$$TC = TC(OF) + 460.0$$

$$VC = VC(FT^3/LB) * WM(LB/LBMOL)$$

$$ZC = PC * VC / R * TC$$


```

C
C GAS COMPOSITION IF KNOWN, SHOULD BE EXPRESSED IN
C PERCENTAGES AND ENTERED IN THE FOLLOWING ORDER
C
C   C1, C2, C3, nC4, iC4, nC5, iC5, C6, C7
C   C8+, CO2, H2S, N2, He
C
C CRITICAL PROPERTIES HAVE BEEN DETERMINED BY KAY'S RULE
C EXCEPT FOR CRITICAL PRESSURE WHICH HAS BEEN
C DETERMINED BY PRAUSNITZ AND GUNN MIXING RULE.
C
C -----
C
C   DIMENSION ZPC(5),ZTC(5),ZERR(5),ZF(5),ZT(5),TT(5)
C   DIMENSION XP(5),X(14),TP(5),ZP(6),F(6)
C   DOUBLE PRECISION ZX1,ZX2,ZX3,VC,SM,SVC,TT,XP,V1,V2,Z,
C   DOUBLE PRECISION G1,G2
C   TR=1.05
C   READ (5,5) NN
5   FORMAT (I2)
C   WRITE (6,10) TR
C   WRITE (7,11) TR
10  FORMAT (2X,'THE FOLLOWING CALCULATIONS ARE FOR A ',
+ 'REDUCED TEMPERATURE OF ',F4.2,//,
+ 2X,'PSEUDO-PRESSURE USING VISCOSITY DETERMINED'
+/,2X,' BY CARR KOBAYASHI BURROWS'//,
+/, 'MIXTURE',3X,'PR',5X,'PRESSURE',
+ 4X,'PSIA2/up',2X,'%DIFF',/,19X,
+ 'PSIA',/)
11  FORMAT (2X,'THE FOLLOWING CALCULATIONS ARE FOR A ',
+ 'REDUCED TEMPERATURE OF ',F4.2,//,
+ 2X,'PSEUDO-PRESSURE USING VISCOSITY DETERMINED'
+/,2X,' BY DEAN & STIEL'//,
+/, 'MIXTURE',3X,'PR',3X,'PRESSURE',
+ 4X,'PSIA2/up',2X,'%DIFF',2X,'%DIFF',2X,'%DIFF',/,19X,
+ 'PSIA',24X,'1-2',3X,'1,5',3X,'1-6',/)
C
C   DO 240 I=1,NN
20  READ (5,30) (X(IJ), IJ=1,14)
30  FORMAT (14(F5.2,1X))
C
C   CALL MIXT(X(1),X(2),X(3),X(4),X(5),X(6),X(7),X(8)
+ ,X(9),X(10),X(11),X(12),X(13),X(14),ZPC(1),ZTC(1),
+ H2S1,CO21,N21,ZPC(2),ZTC(2),H2S2,CO22,N22,
+ ZPC(3),ZTC(3),XG1,XG2,SM1,SM2)
C
C   WRITE (8,32) I,ZPC(1),ZTC(1),ZPC(2),ZTC(2),ZPC(3)
+ ,ZTC(3),SM1,XG1,SM2,XG2
32  FORMAT (I2,2X,12(F9.3,2X))
C

```



```

C  CHECKING UPPER AND LOWER BOUNDARY AS FOLLOWS
C
DO 35 IA=1,3
  ZERR(IA)=0.0
  CALL BOUND (TR,ZTC(IA),XG1,XG2,ZERR(IA),ZT(IA))
35  CONTINUE
C
  PR=0.25
C
C  NATURAL GAS VISCOSITY FACTORS FOR THE DETERMINATION OF
C  DEAN AND STIEL VISCOSITY CORRELATION
C
  IF(TR-1.5) 80,90,90
80  VR=34.0E-05*TR**(8.0/9.0)
  GO TO 100
90  VR=166.8E-05*(0.1338*TR-0.0932)**(5.0/9.0)
100 DO 105 IC=1,3
  TT(IC)=ZTC(IC)*5.0/9.0
  XP(IC)=ZPC(IC)/14.7
105  CONTINUE
  ZX1=TT(1)**(1.0/6.0)/(SM1**0.5*XP(1)**(2.0/3.0))
  ZX2=TT(2)**(1.0/6.0)/(SM1**0.5*XP(2)**(2.0/3.0))
  ZX3=TT(3)**(1.0/6.0)/(SM2**0.5*XP(3)**(2.0/3.0))
C
DO 205 IB=1,50
  IF (PR .LT. 0.01 ) GO TO 160
  IF (PR .GT. 20.0) GO TO 220
C
  CALL ITGR1 (ZPC(1),ZTC(1),PR,TR,XG1,ZT(1),
+H2S1,CO21,N21,FLAG1,ZPC(1),XINTG1)
  CALL ITGR2 (PR,TR,VR,ZX1,ZPC(1),XINTG2)
  CALL ITGR1 (ZPC(2),ZTC(2),PR,TR,XG1,ZT(2),
+H2S1,CO21,N21,FLAG2,ZPC(2),XINTG3)
  CALL ITGR1 (ZPC(3),ZTC(3),PR,TR,XG2,ZT(3),
+H2S2,CO22,N22,FLAG3,ZPC(3),XINTG4)
  CALL ITGR2 (PR,TR,VR,ZX2,ZPC(2),XINTG5)
  CALL ITGR2 (PR,TR,VR,ZX3,ZPC(3),XINTG6)
C
  DIFF1 = (XINTG1-XINTG2)*100.0/XINTG1
  DIFF2 = (XINTG1-XINTG3)*100.0/XINTG1
  DIFF2A= (XINTG2-XINTG3)*100.0/XINTG2
  DIFF3 = (XINTG1-XINTG4)*100.0/XINTG1
  DIFF3A= (XINTG2-XINTG4)*100.0/XINTG2
  DIFF3B= (XINTG3-XINTG4)*100.0/XINTG3
  DIFF4 = (XINTG1-XINTG5)*100.0/XINTG1
  DIFF4A= (XINTG2-XINTG5)*100.0/XINTG2
  DIFF4B= (XINTG3-XINTG5)*100.0/XINTG3
  DIFF4C= (XINTG4-XINTG5)*100.0/XINTG4
  DIFF5 = (XINTG1-XINTG6)*100.0/XINTG1
  DIFF5A= (XINTG2-XINTG6)*100.0/XINTG2
  DIFF5B= (XINTG3-XINTG6)*100.0/XINTG3

```



```

      DIFF5C= (XINTG4-XINTG6)*100.0/XINTG4
      DIFF5D= (XINTG5-XINTG6)*100.0/XINTG5
C
      DO 140 IC=1,3
      ZP(IC) = PR*ZPC(IC)
140  CONTINUE
C
      WRITE(6,155) I,PR,ZP(1),XINTG1,XINTG2,XINTG3,XINTG4
      +,XINTG5,XINTG6,DIFF1,DIFF2,DIFF3,DIFF4,DIFF5
C
      WRITE(7,155) I,PR,ZP(1),DIFF2A,DIFF3A,DIFF4A,
      +DIFF5A,DIFF3B,DIFF4B,DIFF5B,DIFF4C,DIFF5C,DIFF5D
155  FORMAT(2X,I2,4X,F5.2,3X,F8.1,2X,11(F10.4,3X))
C
      IF (PR-0.29)160,165,165
160  PR=PR+0.05
      GO TO 205
165  IF (PR-1.49) 170,175,175
170  PR=PR+0.10
      H=0.02
      GO TO 205
175  IF (PR-2.99) 180,185,185
180  PR=PR+0.50
      H=0.1
      GO TO 205
185  IF (PR-9.99) 190,195,195
190  PR=PR+1.0
      H=0.20
      GO TO 205
195  IF(PR-19.999) 200,240,240
200  PR=PR+5.0
      H=0.5
205  CONTINUE
220  WRITE (6,212)
      WRITE (7,212)
212  FORMAT (' '/')
240  CONTINUE
C
      WRITE (6,211) ZTC(1),ZTC(2),ZTC(3),ZPC(1),ZPC(2),
      +ZPC(3)
      WRITE (7,210) ZT(1)
210  FORMAT (//,'TEMPERATURE IS OUTSIDE RANGE OF CKB',
      +' MODEL WHERE TEMP>860:','/','IT IS ASSUMED THAT
      + VISCOSITY',' CORRELATION BY CKB WILL
      + APPLY','/','WITHIN ACCEPTABLE',
      +' ENGINEERING LIMITS WHEN THESE TEMPERATURES','/
      +'EXCEED THE MODELS RANGE./', 'MIXTURE TEMPERATURE IS
      + ',F7.2,' DEG R',/)
211  FORMAT (//,6(F10.4,2X))
      GO TO 260
C

```



```

250 WRITE(7,255) PR,TR,XG1,XG2,T,Z,M
255 FORMAT ('ERROR WAS DETECTED', 6G12.4)
260 STOP
    END

```

```

C-----
C
    SUBROUTINE MIXT(X1,X2,X3,X4,X5,X6,X7,X8,X9,X10,
+X11,X12,X13,X14,PC1,TC1,H2S1,CO21,N21,PC2,TC2,
+H2S2,CO22,N22,PC3,TC3,G1,G2,SM1,SM2)
C
    DIMENSION TC(14), VC(14), WM(14), ZC(14), ZX(14)
C
    REAL N2
    ZX(1)=X1
    ZX(2)=X2
    ZX(3)=X3
    ZX(4)=X4
    ZX(5)=X5
    ZX(6)=X6
    ZX(7)=X7
    ZX(8)=X8
    ZX(9)=X9
    ZX(10)=X10
    ZX(11)=X11
    ZX(12)=X12
    ZX(13)=X13
    ZX(14)=X14
C
    DATA TC /343.32, 550.10, 666.01, 765.62, 734.96,
+      845.60, 829.03, 913.60, 972.70, 1024.1,
+      547.87, 672.60, 227.30, 9.69/
C
    DATA VC /1.5851, 2.3695, 3.2500, 4.0861, 4.2082,
+      4.8630, 4.8991, 5.9204, 6.9142, 7.8820,
+      1.5051, 1.5675, 1.4455, 0.9207/
C
    DATA WM /16.043, 30.070, 44.097, 58.124, 58.124,
+      72.151, 72.151, 86.178, 100.205, 114.232,
+      44.010, 34.076, 28.013, 4.003/
C
    DATA ZC /0.2876, 0.2844, 0.2805, 0.2742, 0.2826,
+      0.2621, 0.2703, 0.2641, 0.2631, 0.2589,
+      0.2745, 0.2252, 0.2925, 0.2923/
C
    PTC = 0.0
    SZC = 0.0
    SVC = 0.0
    SM1 = 0.0
C
    DO 40 II=1,14

```



```

PTC = PTC + ZX(II) * TC(II)/100.0
SZC = SZC + ZX(II) * ZC(II)/100.0
SVC = SVC + ZX(II) * VC(II)/100.0
SM1 = SM1 + ZX(II) * WM(II)/100.0
40  CONTINUE
C
CO21 = ZX(11)
H2S1 = ZX(12)
N21 = ZX(13)
C
G1=SM1/28.97
R=10.732
PPC = R*PTC*SZC/SVC
TC2=PTC
PC2=PPC
C
IF (CO21 .EQ. 0.0 .AND. H2S1 .EQ. 0.0) GO TO 51
C
CALL WACOR (H2S1,CO21,PPC,PTC,PC1,TC1)
GO TO 52
C
51  TC1=PTC
PC1=PPC
52  TC3 = 0.0
SZC = 0.0
SVC = 0.0
SM2 = 0.0
C
DM=100.0-ZX(11)-ZX(12)-ZX(13)
ZX(11)=0.0
ZX(12)=0.0
ZX(13)=0.0
C
DO 53 II=1,14
TC3 = TC3 + ZX(II) * TC(II)/DM
SZC = SZC + ZX(II) * ZC(II)/DM
SVC = SVC + ZX(II) * VC(II)/DM
SM2 = SM2 + ZX(II) * WM(II)/DM
53  CONTINUE
C
CO22 = 0.0
H2S2 = 0.0
N22 = 0.0
C
G2=SM2/28.97
R=10.732
PC3 = R*TC3*SZC/SVC
C
RETURN
END

```



```

C-----
C
C CORRECTION FOR H2S AND CO2 CONTAMINATION
C BY WICHERT AND AZIZ CORRELATION
C
C SUBROUTINE WACOR (H2S,CO2,PPC,PTC,PC,TC)
C
  A=(CO2+H2S)/100.0
  B=H2S/100.0
  E3=120.0*(A**0.9-A**1.6)+15.0*(B**0.5-B**4.0)
  TC=PTC-E3
  PC=PPC*TC/(PTC+(B*(1-B)*E3))
  RETURN
  END

C-----
C
C SUBROUTINE BOUND (TR,TC,G1,G2,ERR,T)
C
  T=TR*TC
C
C CHECKING UPPER AND LOWER BOUNDARY AS FOLLOWS
C   TR - 1.05 TO 3.00
C   G  - 0.55 TO 1.50
C   T  - 500.0 TO 860.0 DEG R
C
C IF OUTSIDE OF THESE RANGES THEN GO TO PROGRAM'S END
C
  IF (TR .LT. 1.05 .OR. TR .GT. 3.00) ERR=1.0
  IF (G1 .LT. 0.55 .OR. G1 .GT. 1.50) ERR=21.0
  IF (G2 .LT. 0.55 .OR. G2 .GT. 1.50) ERR=22.0
  IF (T .LT. 500.0 .OR. T .GT. 860.0) ERR=3.0
  RETURN
  END

C-----
C
C SUBROUTINE ITGR1 (PC1,TC1,PR,TR,G1,T1,
C +H2S1,CO21,N21,FLAG1,PC,XINTG1)
C
  SUM1=0.0
  PR1=0.20
  H=0.05
  PX1A=0.0
C
C THE FOLLOWING INTERGRALS ARE DONE BY
C TRAPIZODIAL
C
  DO 145 II=1,400
  IF (PR1 .GT. PR) GO TO 150

```



```

CALL ZKATZ (PR1,TR,Z,DR,ITER)
IF (ITER .EQ. 0) FLAG1=0.0
CALL VIS2 (PR1,TR,G1,T1,H2S1,CO21,N21,V2)
PX1 = 2.0*(PR1/(Z*V2))
SUM1 = SUM1 + H*(PX1 + PX1A)/2.0
PX1A = PX1
PR1=PR1+H
145 CONTINUE
C
150 XINTG1 = SUM1*PC**2.0/1000.0
RETURN
END

```

```

C-----
C
SUBROUTINE ITGR2 (PR,TR,VR,ZZI,PC2,XINTG2)
C
H=0.05
SUM2 = 0.0
PX2A = 0.0
PR2 = 0.2
C
C THE FOLLOWING INTERGRALS ARE DONE BY
C TRAPIZODIAL
C
DO 145 II=1,400
IF (PR2.GT.PR) GO TO 150
CALL ZKATZ (PR2,TR,Z,DR,ITER)
CALL VIS1 (ZZI,VR,DR,V1)
PX2 = 2.0*(PR2/(Z*V1))
SUM2 = SUM2 + H*(PX2 + PX2A)/2.0
PX2A = PX2
PR2=PR2+H
145 CONTINUE
C
150 XINTG2 = SUM2*PC2**2.0/1000.0
RETURN
END

```

```

C-----
C
C NATURAL GAS VISCOSITY DETERMINATION USING DEAN AND STIEL
C CORRELATION AS PRESENTED IN AIChE MAY 1965.
C
SUBROUTINE VIS1 (ZI,VR,DR,V1)
C
VG = 10.8E-05*(EXP(1.439*DR)-EXP(-1.11*DR**1.858))
V1 = 10000.0*(VG+VR)/ZI
RETURN
END

```



```

C-----
C
C NATURAL GAS VISCOSITY DETERMINATION USING CARR
C KOBAYASHI AND BURROWS CORRELATION AND LAGRANGE
C INTERPOLATION
C
C SUBROUTINE VIS2 (PR,TR,G,T,H2S,CO2,N2,V2)
C
C DIMENSION TRBL(13), PRBL(22),VBL(22,13), VB1(22,5),
+ VB1A(22,2), VB2(22,6)
C
C EQUIVALENCE (VB1(1,1),VBL(1,1)),(VB1A(1,1), VBL(1,6)),
+ (VB2(1,1), VBL(1,8))
C
C DATA TRBL /
+ 1.05, 1.10, 1.15, 1.20, 1.30, 1.40, 1.50,
+ 1.60, 1.75, 2.00, 2.25, 2.50, 3.00/
C
C DATA PRBL /
+ 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.2
+, 1.4, 1.6, 1.8, 2.0, 3.0, 4.0, 6.0, 8.0, 10.0, 15.0,
+ 20.0/
C
C DATA VB1 /
+1.000,1.012,1.025,1.050,1.075,1.100,1.145,1.195,1.285,
+1.415,1.760,2.285,2.865,3.290,3.650,4.760,5.500,6.460,
+7.150,7.680,8.650,9.370,
+1.000,1.011,1.023,1.043,1.065,1.086,1.120,1.150,1.195,
+1.255,1.435,1.700,2.070,2.465,2.800,3.850,4.655,5.720,
+6.500,7.060,8.100,8.880,
+1.000,1.010,1.021,1.036,1.055,1.073,1.095,1.120,1.145,
+1.175,1.280,1.420,1.590,1.850,2.160,3.225,3.975,5.030,
+5.820,6.385,7.410,8.180,
+1.000,1.009,1.019,1.030,1.045,1.060,1.070,1.085,1.110,
+1.135,1.195,1.285,1.425,1.570,1.750,2.600,3.350,4.380,
+5.125,5.740,6.750,7.500,
+1.000,1.008,1.017,1.027,1.040,1.054,1.063,1.075,1.100,
+1.120,1.155,1.215,1.285,1.360,1.460,2.020,2.560,3.500,
+4.185,4.755,5.790,6.500/
C
C DATA VB1A /
+1.000,1.007,1.015,1.024,1.035,1.048,1.056,1.067,1.089,
+1.100,1.135,1.185,1.235,1.280,1.335,1.690,2.110,2.790,
+3.380,3.860,4.790,5.410,
+1.000,1.006,1.013,1.021,1.030,1.042,1.049,1.059,1.076,
+1.100,1.120,1.150,1.185,1.220,1.260,1.500,1.785,2.325,
+2.820,3.230,4.060,4.610/
C
C DATA VB2 /
+1.000,1.005,1.011,1.018,1.025,1.036,1.042,1.051,1.067,
+1.070,1.095,1.120,1.150,1.180,1.215,1.385,1.595,2.030,

```



```

+2.425,2.770,3.490,4.025,
+1.000,1.004,1.009,1.015,1.021,1.030,1.035,1.043,1.056,
+1.065,1.090,1.110,1.125,1.145,1.165,1.280,1.435,1.770,
+2.095,2.375,2.990,3.500,
+1.000,1.003,1.007,1.012,1.017,1.024,1.028,1.035,1.045,
+1.055,1.060,1.070,1.080,1.095,1.110,1.205,1.290,1.500,
+1.725,1.955,2.480,2.925,
+1.000,1.002,1.005,1.009,1.013,1.018,1.021,1.027,1.034,
+1.040,1.045,1.055,1.065,1.075,1.085,1.145,1.210,1.340,
+1.485,1.665,2.085,2.460,
+1.000,1.001,1.003,1.006,1.009,1.012,1.015,1.019,1.023,
+1.025,1.030,1.040,1.050,1.060,1.065,1.105,1.155,1.245,
+1.360,1.485,1.830,2.150,
+1.000,1.000,1.001,1.003,1.005,1.007,1.009,1.011,1.013,
+1.015,1.020,1.025,1.030,1.035,1.040,1.060,1.085,1.140,
+1.205,1.265,1.495,1.750/

```

```

C
C
C   INITIALIZING UPPER AND LOWER BOUNDARIES FOR THE
C   LOOK-UP TABLES
C

```

```

LOPR = 2
LOTR = 3
IHIPR = 21
IHITR = 11
IERR = 0

```

```

C
C   LOCATE TR IN INDEX
C
DO 100 J = LOTR,IHITR
IF (TRBL(J) .GE. TR) GO TO 120
100 CONTINUE
J = IHITR+1

```

```

C
C   CHECK PR AGAINST INDEX
C
C   IF PR<0.01; PROFORM LAGRANGE INTERPOLATION
C   USING RATIO FOR PR=0.01
C
C   IF PR>20.0; PROFORM LAGRANGE INTERPOLATION
C   USING RATIO FOR PR=20.0
C
C   OTHERWISE LOCATE PR
C

```

```

120 IF (PRBL(LOPR-1) .LT. PR) GO TO 160
I = 1
ICALL = 1
GO TO 320
140 VISR = 1.0+(PR*(VISI-1.0))
GO TO 300
160 IF (PRBL(IHIPR+1) .GT. PR) GO TO 200

```



```

      I = IHIPR+1
      ICALL = 2
      GO TO 320
180  VISR = VISI
      GO TO 300
200  DO 220 I = LOPR,IHIPR
      IF (PRBL(I) .GE. PR) GO TO 240
220  CONTINUE
      I = IHIPR+1
240  ICALL = 3
      GO TO 320
260  VISJ = VISI
      I = I-1
      ICALL = 4
      GO TO 320
280  I = I+1
      VISR = VISI+((PR-PRBL(I-1))/(PRBL(I)-PRBL(I-1)))*
+      (VISJ-VISI)
C
C  CORRECTION FOR H2S, CO2, AND N2
C
300  NT = T-460.0
      VISU = 0.126585E-01-0.611823E-02*G+0.164574E-02*G**2.0
+      +0.164574E-04*NT-0.719221E-06*G*NT-0.609046E-06*
+      G**2.0*NT
      CORH2S = (0.113E-03*H2S*G-0.38E-04*H2S+0.10E-05)*
+      (1.0/(1.0+G))+0.10E-05
      CORCO2 = (0.134E-03*CO2*G-0.40E-05*CO2+0.40E-05*G)*
+      (1.0/(1.0+G))-0.30E-05
      CORN2 = (0.170E-03*N2*G+0.21E-04*N2+0.10E-04*G)*
+      (1.0/(1.0+G))-0.60E-05
      VISA = VISU+CORH2S+CORCO2+CORN2
      V2 = 10000.0*VISR*VISA
C
      GO TO 360
C
C  CALL LAGRANGE INTERPOLATION
C
320  CALL XLGR4(TR,TRBL(J-2),TRBL(J-1),TRBL(J),TRBL(J+1),
+      VISI,VBL(I,J-2),VBL(I,J-1),VBL(I,J),VBL(I,J+1))
      GO TO (140,180,260,280), ICALL
340  IERR = 1
      VISR = 0.0
      V2 = 0.0
360  RETURN
      END

C-----
C
C  SUBROUTINE XLGR4(X,X1,X2,X3,X4,Y,Y1,Y2,Y3,Y4)
C

```



```

A1 = X1-X2
A2 = X1-X3
A3 = X1-X4
A4 = X2-X3
A5 = X2-X4
A6 = X3-X4
B1 = X-X1
B2 = X-X2
B3 = X-X3
B4 = X-X4
Y = B2/A1*B3/A2*B4/A3*Y1-B1/A1*B3/A4*B4/A5*Y2+
+ B1/A2*B2/A4*B4/A6*Y3-B1/A3*B2/A5*B3/A6*Y4
RETURN
END

```

```

C-----
C
C SUBROUTINE ZKATZ(PR,TR,Z,DR,ITER)
C
C DIMENSION A(8)
C DATA A/0.31506237,-1.0467099,-0.57832729,0.53530771,
+ -0.6123032,-0.10488813,0.68157001,0.68446549/
C ITER = 0
C DR = 1.0
C IF(TR-1.05)100,10,10
10 IF(TR-3.0)20,20,100
20 IF(PR-30.0)30,30,100
30 DO 80 ITER = 1,10
C DR2 = DR**2
C T1 = (A(1)*TR+A(2)+A(3)/TR**2)*DR
C T2 = (A(4)*TR+A(5))*DR2
C T3 = A(5)*A(6)*DR**5
C T4 = A(7)*DR2/TR**2
C T5 = A(8)*DR2
C T6 = EXP(-T5)
C P = (TR+T1+T2+T3)*DR+T4*DR*(1.0+T5)*T6
C DP = TR+2.0*T1+3.0*T2+6.0*T3+T4*T6*(3.0+3.0*
+ T5-2.0*T5**2)
C DR1 = DR-(P-0.270*PR)/DP
C IF(DR1)40,40,50
40 DR1 = 0.5*DR
50 IF(DR1-2.2)70,70,60
60 DR1 = DR+0.9*(2.2-DR)
70 IF(ABS(DR-DR1)-0.1E-04)90,80,80
80 DR = DR1
90 Z = 0.270*PR/(DR1*TR)
C DR = 0.270*PR/(Z*TR)
C DZ = A(1)+A(2)/TR+A(3)/TR**3 + 2.0*(A(4)+A(5)/TR)*DR +
+ 5.0*A(5)*A(6)*DR**4/TR + (1.0+A(8)*DR**2-
+ A(8)**2**DR**4)*2.0*A(7)*DR/TR**3*EXP(-A(8)*
+ DR**2)

```



```
      CR = 1.0/PR -0.270*DZ/(Z**2*TR*(1.0 + DR/Z*DZ))  
100 RETURN  
END
```


APPENDIX VI

ACTUAL FIELD PRODUCTION TESTS

Banff et al Ricinus
06-25-036-10 W5M
Ricinus West/Leduc D-3
Jan 22 - Feb 4 / 1970

THE FOLLOWING IS A COMPARISON BETWEEN TWO METHODS OF CALCULATING PSEUDO GAS PRESSURE USING CARR, KOBAYASHI AND BURROW VISCOSITY CORRELATION, AS METHOD 1, AND USING DEAN AND STIEL VISCOSITY CORRELATION, METHODS 2.

SUBSCRIPT A INCLUDE ALL CORRECTION FACTORS AVAIABLE, WHILE METHODS B, EXCLUDES THESE CORRECTION FACTORS. METHODS C PROVIDES ANALYSIS ON NON-HYDROCARBON FREE GASES.

CALCULATIONS ARE FOR A RESERVOIR TEMPERATURE OF 708.00 DEG R. REDUCED TEMPERATURES FOR THESE METHODS ARE:

TrA=1.7790
TrB=1.6419
TrC=2.0487

AOF History

Time hrs	Homer Ratio	Flow Rates Mscf/d	Pressures		Psuedo Gas Pressure (Psi2/μp)€3								
			Psig	Psig2	PrA	1A	2A	PrB	1B	2B	PrC	1C	2C
0.000	0.0000	0.0000	5761.3008	33.1922	7.670	168.443	143.514	6.961	171.506	188.610	8.612	172.402	174.036
12.000	0.0000	19.4880	5684.5000	32.3131	7.567	165.240	140.764	6.868	168.282	185.080	8.497	168.972	170.546
12.000	0.0000	0.0000	5761.3008	33.1922	7.670	168.443	143.514	6.961	171.506	188.610	8.612	172.402	174.036
12.000	0.0000	26.2500	5639.0000	31.7981	7.507	163.343	139.136	6.813	166.372	182.989	8.429	166.943	168.483
12.000	0.0000	0.0000	5761.3008	33.1922	7.670	168.443	143.514	6.961	171.506	188.610	8.612	172.402	174.036
12.000	0.0000	31.9640	5583.1016	31.1707	7.432	161.015	137.137	6.745	164.026	180.420	8.345	164.453	165.952
12.000	0.0000	0.0000	5461.3008	29.8256	7.270	155.944	132.788	6.598	158.918	174.824	8.163	159.041	160.457
12.000	0.0000	39.3719	5464.6992	29.8629	7.275	156.086	132.909	6.602	159.060	174.980	8.168	159.191	160.610
12.000	0.0000	0.0000	5761.3008	33.1922	7.670	168.443	143.514	6.961	171.506	188.610	8.612	172.402	174.036
12.000	0.0000	26.6829	5649.3984	31.9157	7.521	163.776	139.508	6.825	166.808	183.467	8.444	167.406	168.954
43.500	0.0000	29.9049	5649.3984	31.9157	7.521	163.776	139.508	6.825	166.808	183.467	8.444	167.406	168.954

Build Up	0.000	0.0000	0.0000	5649.3984	31.9157	7.521	163.776	139.508	6.825	166.808	183.467	8.444	167.406	168.954
0.000	0.0000	0.0000	0.0000	5741.5000	32.9655	7.643	167.618	142.805	6.937	170.675	187.700	8.582	171.517	173.134
0.250	179.0000	0.0000	0.0000	5747.0000	33.0280	7.651	167.846	143.002	6.943	170.906	187.952	8.590	171.763	173.385
0.500	90.0000	0.0000	0.0000	5752.5000	33.0910	7.658	168.076	143.199	6.950	171.136	188.205	8.598	172.009	173.636
0.750	60.3333	0.0000	0.0000	5754.6992	33.1163	7.661	168.168	143.278	6.953	171.229	188.306	8.602	172.108	173.736
1.000	45.5000	0.0000	0.0000	5756.8008	33.1406	7.664	168.255	143.353	6.955	171.317	188.403	8.605	172.201	173.831
1.500	30.6666	0.0000	0.0000	5757.5000	33.1487	7.665	168.284	143.378	6.956	171.346	188.435	8.606	172.233	173.864
2.000	23.2500	0.0000	0.0000	5758.6016	33.1613	7.666	168.331	143.418	6.957	171.392	188.485	8.608	172.282	173.913
2.500	18.7999	0.0000	0.0000	5759.6992	33.1740	7.668	168.376	143.457	6.959	171.438	188.536	8.609	172.331	173.963
3.500	13.7142	0.0000	0.0000	5759.6992	33.1740	7.668	168.376	143.457	6.959	171.438	188.536	8.609	172.331	173.963
7.500	6.9333	0.0000	0.0000	5759.6992	33.1740	7.668	168.376	143.457	6.959	171.438	188.536	8.609	172.331	173.963

THE FOLLOWING IS A COMPARISON OF THE DIFFERENCES BETWEEN TWO METHODS OF CALCULATING PSEUDO GAS PRESSURE. ALL DIFFERENCES ARE EXPRESSED IN PERCENT.

PRESSURES		1A-2A	1A-1B	1A-1C	2A-2B	2A-2C	1B-2B	1C-2C
PSIA								
5761.3008	14.8009	-1.5901	-2.4077	-2.4077	-3.1734	-21.0639	13.4731	-0.7203
5761.3008	14.7994	-1.8184	-2.3510	-2.3510	-31.4223	-21.2679	-9.9727	-0.9476
5684.5000	14.8119	-1.8409	-2.2590	-2.2590	-31.4824	-21.1575	-9.9826	-0.9315
5761.3008	14.7994	-1.8184	-2.3510	-2.3510	-31.4223	-21.2679	-9.9727	-0.9476
5639.0000	14.8196	-1.8543	-2.2042	-2.2042	-31.5181	-21.0926	-9.9880	-0.9225
5761.3008	14.7994	-1.8184	-2.3510	-2.3510	-31.4223	-21.2679	-9.9727	-0.9476
5583.1016	14.8291	-1.8700	-2.1358	-2.1358	-31.5613	-21.0121	-9.9949	-0.9117
5461.3008	14.8491	-1.9073	-1.9861	-1.9861	-31.6572	-20.8379	-10.0090	-0.8907
5464.6992	14.8486	-1.9055	-1.9895	-1.9895	-31.6538	-20.8421	-10.0087	-0.8914
5761.3008	14.7994	-1.8184	-2.3510	-2.3510	-31.4223	-21.2679	-9.9727	-0.9476
5649.3984	14.8179	-1.8510	-2.2165	-2.2165	-31.5096	-21.1075	-9.9867	-0.9247
5649.3984	14.8179	-1.8510	-2.2165	-2.2165	-31.5096	-21.1075	-9.9867	-0.9247
5649.3984	14.8179	-1.8510	-2.2165	-2.2165	-31.5096	-21.1075	-9.9867	-0.9247
5741.5000	14.8031	-1.8237	-2.3266	-2.3266	-31.4377	-21.2388	-9.9751	-0.9430
5747.0000	14.8019	-1.8228	-2.3337	-2.3337	-31.4336	-21.2474	-9.9742	-0.9446
5752.5000	14.8007	-1.8208	-2.3406	-2.3406	-31.4287	-21.2551	-9.9738	-0.9457
5754.6992	14.8007	-1.8202	-2.3430	-2.3430	-31.4274	-21.2580	-9.9734	-0.9457
5756.8008	14.7999	-1.8198	-2.3456	-2.3456	-31.4259	-21.2612	-9.9737	-0.9468
5757.5000	14.7998	-1.8192	-2.3466	-2.3466	-31.4251	-21.2624	-9.9736	-0.9468
5758.6016	14.8000	-1.8186	-2.3475	-2.3475	-31.4241	-21.2639	-9.9732	-0.9471
5759.6992	14.7997	-1.8189	-2.3492	-2.3492	-31.4237	-21.2657	-9.9729	-0.9471
5759.6992	14.7997	-1.8189	-2.3492	-2.3492	-31.4237	-21.2657	-9.9729	-0.9471

Banff Aquit Ricinus West
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Sep 16 - 27 / 1970

THE FOLLOWING IS A COMPARISON BETWEEN TWO METHODS OF CALCULATING PSEUDO GAS PRESSURE USING CARR, KOBAYASHI AND BURROW VISCOSITY CORRELATION, AS METHOD 1, AND USING DEAN AND STIEL VISCOSITY CORRELATION, METHODS 2.

SUBSCRIPT A INCLUDE ALL CORRECTION FACTORS AVAILABLE, WHILE METHODS B, EXCLUDES THESE CORRECTION FACTORS. METHODS C PROVIDES ANALYSIS ON NON-HYDROCARBON FREE GASES.

CALCULATIONS ARE FOR A RESERVOIR TEMPERATURE OF 708.00 DEG R. REDUCED TEMPERATURES FOR THESE METHODS

ARE: TrA=1.7790
TrB=1.6419
TrC=2.0487

AOF History

Time		Flow Rates		Pressures		Pseudo Gas Pressure (Psi2/μp)£3							
hrs	Horner Ratio	Mscf/d	Psig	Psig2	PrA	1A	2A	PrB	1B	2B	PrC	1C	2C
0.000	0.0000	0.0000	5771.6015	33.3114	7.603	168.033	143.276	6.900	171.796	189.819	8.655	172.901	174.733
6.000	0.0000	14.3880	5652.1015	31.9459	7.445	163.137	139.084	6.757	166.869	184.412	8.476	167.619	169.348
6.000	0.0000	0.0000	5771.6015	33.3114	7.603	168.033	143.276	6.900	171.796	189.819	8.655	172.901	174.733
6.000	0.0000	21.7860	5539.0000	30.6804	7.296	158.504	135.120	6.622	162.204	179.290	8.306	162.633	164.271
6.000	0.0000	0.0000	5772.8984	33.3261	7.605	168.086	143.321	6.902	171.849	189.879	8.657	172.959	174.791
6.000	0.0000	28.4630	5416.8007	29.3416	7.136	153.503	130.842	6.476	157.165	173.755	8.123	157.261	158.805
6.000	0.0000	0.0000	5771.1992	33.3063	7.602	168.016	143.261	6.900	171.779	189.801	8.654	172.884	174.715
6.000	0.0000	34.5020	5299.8984	28.0887	6.981	148.725	126.754	6.336	152.347	168.458	7.947	152.139	153.600
57.500	0.0000	21.8360	5546.3984	30.7624	7.306	158.808	135.379	6.631	162.509	179.626	8.317	162.958	164.601
Build Up													
0.000	0.0000	0.0000	5546.3984	30.7624	7.306	158.808	135.379	6.631	162.509	179.626	8.317	162.958	164.601
0.250	235.0000	0.0000	5707.5000	32.5755	7.518	165.406	141.026	6.824	169.153	186.920	8.559	170.066	171.842
0.500	118.0000	0.0000	5735.3984	32.8947	7.555	166.550	142.005	6.857	170.303	188.182	8.600	171.300	173.099
0.750	79.0000	0.0000	5748.5000	33.0451	7.572	167.087	142.465	6.873	170.843	188.775	8.620	171.879	173.690
1.000	59.5000	0.0000	5753.3007	33.1001	7.579	167.284	142.633	6.878	171.041	188.992	8.627	172.092	173.907
1.250	47.7999	0.0000	5759.3984	33.1704	7.587	167.533	142.847	6.886	171.293	189.268	8.636	172.362	174.182

1.750	34.4285	0.0000	5759.8007	33.1749	7.587	167.550	142.861	6.886	171.309	189.286	8.637	172.379	174.200
2.000	30.2500	0.0000	5762.0000	33.2003	7.590	167.639	142.938	6.889	171.400	189.385	8.640	172.476	174.299
2.250	27.0000	0.0000	5762.8984	33.2109	7.591	167.677	142.970	6.890	171.437	189.426	8.642	172.516	174.340
2.500	24.3999	0.0000	5764.6015	33.2301	7.594	167.747	143.030	6.892	171.507	189.503	8.644	172.591	174.416
2.750	22.2727	0.0000	5766.0000	33.2464	7.596	167.804	143.079	6.893	171.565	189.566	8.646	172.654	174.480
3.000	20.5000	0.0000	5766.8007	33.2555	7.597	167.837	143.107	6.894	171.598	189.602	8.648	172.689	174.516
3.250	19.0000	0.0000	5768.1015	33.2707	7.598	167.890	143.152	6.896	171.652	189.661	8.649	172.747	174.574
3.500	17.7142	0.0000	5769.3984	33.2855	7.600	167.943	143.198	6.898	171.705	189.720	8.651	172.804	174.633
3.750	16.5999	0.0000	5769.8984	33.2916	7.601	167.964	143.216	6.898	171.726	189.742	8.652	172.827	174.655
4.000	15.6250	0.0000	5770.3007	33.2961	7.601	167.980	143.230	6.899	171.742	189.760	8.653	172.845	174.674
4.250	14.7647	0.0000	5770.8007	33.3017	7.602	168.000	143.247	6.899	171.763	189.783	8.654	172.866	174.697
4.500	14.0000	0.0000	5771.1992	33.3063	7.602	168.016	143.261	6.900	171.779	189.801	8.654	172.884	174.715

THE FOLLOWING IS A COMPARISON OF THE DIFFERENCES BETWEEN TWO METHODS OF CALCULATING PSEUDO GAS PRESSURE. ALL DIFFERENCES ARE EXPRESSED IN PERCENT.

PRESSURES		1A-2A	1A-1B	1A-1C	2A-2B	2A-2C	1B-2B	1C-2C
PSIA								
5771.6015	14.7336	-2.2390	-2.8971	-2.8971	-32.4852	-21.9553	-10.4913	-1.0591
5652.1015	14.7437	-2.2876	-2.7477	-2.7477	-32.5904	-21.7595	-10.5134	-1.0314
5771.6015	14.7336	-2.2390	-2.8971	-2.8971	-32.4852	-21.9553	-10.4913	-1.0591
5539.0000	14.7531	-2.3341	-2.6048	-2.6048	-32.6896	-21.5740	-10.5337	-1.0069
5772.8984	14.7336	-2.2388	-2.8987	-2.8987	-32.4850	-21.9575	-10.4914	-1.0592
5416.8007	14.7626	-2.3858	-2.4481	-2.4481	-32.7976	-21.3720	-10.5555	-0.9821
5771.1992	14.7337	-2.2396	-2.8968	-2.8968	-32.4860	-21.9552	-10.4913	-1.0590
5299.8984	14.7729	-2.4352	-2.2951	-2.2951	-32.9014	-21.1795	-10.5751	-0.9605
5546.3984	14.7527	-2.3308	-2.6137	-2.6137	-32.6834	-21.5854	-10.5326	-1.0082
5546.3984	14.7527	-2.3308	-2.6137	-2.6137	-32.6834	-21.5854	-10.5326	-1.0082
5707.5000	14.7394	-2.2648	-2.8172	-2.8172	-32.5420	-21.8507	-10.5033	-1.0440
5735.3984	14.7372	-2.2536	-2.8518	-2.8518	-32.5175	-21.8966	-10.4979	-1.0505
5748.5000	14.7361	-2.2480	-2.8678	-2.8678	-32.5063	-21.9178	-10.4960	-1.0537
5753.3007	14.7355	-2.2461	-2.8745	-2.8745	-32.5017	-21.9258	-10.4949	-1.0546
5759.3984	14.7348	-2.2441	-2.8821	-2.8821	-32.4962	-21.9358	-10.4935	-1.0561
5759.8007	14.7347	-2.2439	-2.8824	-2.8824	-32.4960	-21.9363	-10.4936	-1.0563
5762.0000	14.7347	-2.2430	-2.8853	-2.8853	-32.4942	-21.9402	-10.4932	-1.0569
5762.8984	14.7347	-2.2426	-2.8863	-2.8863	-32.4935	-21.9413	-10.4930	-1.0568
5764.6015	14.7346	-2.2418	-2.8881	-2.8881	-32.4921	-21.9441	-10.4928	-1.0574
5766.0000	14.7343	-2.2414	-2.8902	-2.8902	-32.4905	-21.9466	-10.4922	-1.0577
5766.8007	14.7344	-2.2411	-2.8908	-2.8908	-32.4899	-21.9477	-10.4920	-1.0579

5768.1015	14.7341	-2.2408	-2.8930	-32.4889	-21.9500	-10.4918	-1.0580
5769.3984	14.7342	-2.2399	-2.8941	-32.4876	-21.9519	-10.4916	-1.0584
5769.8984	14.7341	-2.2396	-2.8950	-32.4869	-21.9526	-10.4916	-1.0582
5770.3007	14.7341	-2.2396	-2.8959	-32.4868	-21.9538	-10.4914	-1.0584
5770.8007	14.7338	-2.2397	-2.8961	-32.4865	-21.9546	-10.4913	-1.0591
5771.1992	14.7337	-2.2396	-2.8968	-32.4860	-21.9552	-10.4913	-1.0590

1.750	9.0000	0.0000	5461.8984	29.8319	7.264	155.275	132.682	6.596	158.460	174.482	8.165	158.711	159.912
2.000	8.0000	0.0000	5485.6015	30.0916	7.296	156.261	133.531	6.625	159.456	175.574	8.200	159.767	160.981
2.500	6.5999	0.0000	5521.1015	30.4825	7.343	157.738	134.803	6.668	160.947	177.211	8.253	161.348	162.583
3.000	5.6666	0.0000	5553.1992	30.8376	7.386	159.075	135.954	6.707	162.296	178.691	8.301	162.779	164.033
3.500	5.0000	0.0000	5575.6015	31.0871	7.415	160.007	136.758	6.734	163.238	179.725	8.335	163.779	165.046
4.000	4.5000	0.0000	5595.0000	31.3036	7.441	160.816	137.455	6.757	164.053	180.620	8.364	164.645	165.925
4.500	4.1111	0.0000	5613.0000	31.5054	7.465	161.566	138.100	6.779	164.810	181.449	8.391	165.449	166.741
5.000	3.7999	0.0000	5632.8007	31.7283	7.492	162.391	138.811	6.803	165.643	182.363	8.420	166.334	167.637
5.500	3.5454	0.0000	5640.5000	31.8150	7.502	162.712	139.088	6.812	165.967	182.719	8.432	166.678	167.987
6.000	3.3333	0.0000	5655.5000	31.9844	7.522	163.337	139.627	6.830	166.597	183.411	8.454	167.349	168.667
7.000	3.0000	0.0000	5670.3984	32.1533	7.542	163.959	140.162	6.848	167.224	184.098	8.476	168.016	169.344
8.000	2.7500	0.0000	5684.8007	32.3166	7.561	164.559	140.680	6.866	167.830	184.763	8.498	168.660	169.998
9.000	2.5555	0.0000	5694.0000	32.4213	7.573	164.943	141.010	6.877	168.217	185.187	8.512	169.073	170.416
10.000	2.3999	0.0000	5702.1015	32.5139	7.584	165.281	141.301	6.886	168.558	185.560	8.524	169.435	170.784
11.000	2.2727	0.0000	5709.1992	32.5949	7.593	165.577	141.556	6.895	168.857	185.889	8.534	169.753	171.108
12.000	2.1666	0.0000	5712.3007	32.6302	7.597	165.706	141.668	6.899	168.987	186.031	8.539	169.892	171.248

THE FOLLOWING IS A COMPARISON OF THE DIFFERENCES BETWEEN TWO METHODS OF CALCULATING PSEUDO GAS PRESSURE. ALL DIFFERENCES ARE EXPRESSED IN PERCENT.

PRESSURES													
PSIA		1A-2A	1A-1B	1A-1C	2A-2B	2A-2C	1B-2B	1C-2C					
5741.3984	14.5009	14.5009	-1.9718	-2.5609	-31.2925	-20.9204	-10.0831	-0.8042					
5564.6015	14.5324	14.5324	-2.0214	-2.3431	-31.4259	-20.6693	-10.1010	-0.7719					
5738.5000	14.5014	14.5014	-1.9728	-2.5583	-31.2953	-20.9170	-10.0838	-0.8035					
5449.1015	14.5525	14.5525	-2.0552	-2.1968	-31.5133	-20.5043	-10.1117	-0.7545					
5732.6015	14.5028	14.5028	-1.9740	-2.5504	-31.2993	-20.9085	-10.0841	-0.8024					
5119.6015	14.6110	14.6110	-2.1559	-1.7674	-31.7598	-20.0369	-10.1339	-0.7181					
5718.5000	14.5050	14.5050	-1.9782	-2.5334	-31.3102	-20.8886	-10.0859	-0.7999					
4214.1992	14.7906	14.7906	-2.3984	-0.5740	-32.3744	-18.8105	-10.1534	-0.6597					
4163.8007	14.8017	14.8017	-2.4064	-0.5082	-32.4037	-18.7472	-10.1548	-0.6589					
5206.6992	14.5952	14.5952	-2.1282	-1.8818	-31.6950	-20.1602	-10.1300	-0.7270					
5212.0000	14.5943	14.5943	-2.1265	-1.8885	-31.6907	-20.1674	-10.1294	-0.7274					
5298.8984	14.5789	14.5789	-2.1003	-2.0028	-31.6267	-20.2915	-10.1239	-0.7367					
5330.3984	14.5735	14.5735	-2.0903	-2.0433	-31.6026	-20.3359	-10.1215	-0.7402					
5399.3984	14.5611	14.5611	-2.0701	-2.1332	-31.5504	-20.4333	-10.1156	-0.7477					
5432.8984	14.5557	14.5557	-2.0597	-2.1756	-31.5256	-20.4814	-10.1130	-0.7525					
5461.8984	14.5502	14.5502	-2.0514	-2.2129	-31.5039	-20.5224	-10.1109	-0.7564					

5485.6015	14.5462	-2.0444	-2.2436	-31.4858	-20.5570	-10.1084	-0.7597
5521.1015	14.5399	-2.0344	-2.2887	-31.4593	-20.6078	-10.1052	-0.7653
5553.1992	14.5341	-2.0250	-2.3283	-31.4346	-20.6525	-10.1021	-0.7703
5575.6015	14.5303	-2.0187	-2.3569	-31.4181	-20.6850	-10.0999	-0.7739
5595.0000	14.5268	-2.0130	-2.3807	-31.4032	-20.7123	-10.0981	-0.7774
5613.0000	14.5238	-2.0076	-2.4036	-31.3894	-20.7386	-10.0962	-0.7803
5632.8007	14.5203	-2.0022	-2.4277	-31.3748	-20.7660	-10.0943	-0.7836
5640.5000	14.5189	-2.0003	-2.4374	-31.3696	-20.7774	-10.0938	-0.7851
5655.5000	14.5161	-1.9957	-2.4560	-31.3578	-20.7982	-10.0925	-0.7875
5670.3984	14.5136	-1.9915	-2.4744	-31.3463	-20.8197	-10.0907	-0.7904
5684.8007	14.5108	-1.9875	-2.4921	-31.3351	-20.8401	-10.0893	-0.7933
5694.0000	14.5096	-1.9849	-2.5037	-31.3287	-20.8539	-10.0881	-0.7947
5702.1015	14.5082	-1.9825	-2.5134	-31.3222	-20.8652	-10.0870	-0.7962
5709.1992	14.5070	-1.9808	-2.5220	-31.3176	-20.8757	-10.0866	-0.7981
5712.3007	14.5062	-1.9796	-2.5259	-31.3143	-20.8796	-10.0862	-0.7983

12.000	4.4916	0.0000	4402.8984	19.3853	5.811	112.127	95.008	5.271	115.100	127.042	6.595	113.161	113.945
16.000	3.6187	0.0000	4403.8984	19.3942	5.812	112.167	95.042	5.272	115.140	127.087	6.597	113.202	113.987
20.000	3.0949	0.0000	4403.8984	19.3942	5.812	112.167	95.042	5.272	115.140	127.087	6.597	113.202	113.987
26.000	2.6115	0.0000	4403.8984	19.3942	5.812	112.167	95.042	5.272	115.140	127.087	6.597	113.202	113.987
32.000	2.3093	0.0000	4403.8984	19.3942	5.812	112.167	95.042	5.272	115.140	127.087	6.597	113.202	113.987
38.000	2.1026	0.0000	4403.8984	19.3942	5.812	112.167	95.042	5.272	115.140	127.087	6.597	113.202	113.987
42.830	1.9782	0.0000	4403.8984	19.3942	5.812	112.167	95.042	5.272	115.140	127.087	6.597	113.202	113.987

THE FOLLOWING IS A COMPARISON OF THE DIFFERENCES BETWEEN TWO METHODS OF CALCULATING PSEUDO GAS PRESSURE. ALL DIFFERENCES ARE EXPRESSED IN PERCENT.

PRESSURES													
PSIA													
	1A-2A	1A-1B	1A-1C	2A-2B	2A-2C	1B-2B	1C-2C						
4403.0000	15.2678	-2.6509	-0.9222	-33.7172	-19.9324	-10.3754	-0.6926						
4371.8007	15.2737	-2.6578	-0.8797	-33.7390	-19.8876	-10.3783	-0.6905						
4399.3984	15.2684	-2.6514	-0.9169	-33.7190	-19.9268	-10.3757	-0.6925						
4345.6992	15.2791	-2.6632	-0.8438	-33.7577	-19.8507	-10.3808	-0.6887						
4398.6015	15.2687	-2.6519	-0.9165	-33.7206	-19.9262	-10.3759	-0.6921						
4264.0000	15.2952	-2.6796	-0.7333	-33.8143	-19.7356	-10.3891	-0.6834						
4396.1992	15.2692	-2.6525	-0.9126	-33.7227	-19.9224	-10.3765	-0.6922						
4194.3984	15.3093	-2.6921	-0.6396	-33.8616	-19.6392	-10.3962	-0.6793						
4214.6015	15.3051	-2.6894	-0.6668	-33.8487	-19.6673	-10.3939	-0.6806						
4386.5000	15.2709	-2.6546	-0.8998	-33.7287	-19.9086	-10.3769	-0.6913						
4395.1992	15.2693	-2.6524	-0.9113	-33.7227	-19.9211	-10.3765	-0.6922						
4399.3984	15.2684	-2.6514	-0.9169	-33.7190	-19.9268	-10.3757	-0.6925						
4401.8007	15.2680	-2.6511	-0.9204	-33.7176	-19.9306	-10.3754	-0.6927						
4402.1992	15.2678	-2.6515	-0.9210	-33.7185	-19.9312	-10.3759	-0.6928						
4402.8984	15.2679	-2.6508	-0.9219	-33.7174	-19.9324	-10.3757	-0.6928						
4403.8984	15.2675	-2.6505	-0.9231	-33.7165	-19.9337	-10.3757	-0.6931						
4403.8984	15.2675	-2.6505	-0.9231	-33.7165	-19.9337	-10.3757	-0.6931						
4403.8984	15.2675	-2.6505	-0.9231	-33.7165	-19.9337	-10.3757	-0.6931						
4403.8984	15.2675	-2.6505	-0.9231	-33.7165	-19.9337	-10.3757	-0.6931						
4403.8984	15.2675	-2.6505	-0.9231	-33.7165	-19.9337	-10.3757	-0.6931						
4403.8984	15.2675	-2.6505	-0.9231	-33.7165	-19.9337	-10.3757	-0.6931						

Banff Aquit Ricinus 10-33
10-33-036-10 W5M
Ricinus West/Leduc D-3
Aug 23 - Sep 13 / 1970

THE FOLLOWING IS A COMPARISON BETWEEN TWO METHODS OF CALCULATING PSEUDO GAS PRESSURE USING CARR, KOBAYASHI AND BURROW VISCOSITY CORRELATION, AS METHOD 1, AND USING DEAN AND STIEL VISCOSITY CORRELATION, METHODS 2.

SUBSCRIPT A INCLUDE ALL CORRECTION FACTORS AVAILABLE, WHILE METHODS B, EXCLUDES THESE CORRECTION FACTORS. METHODS C PROVIDES ANALYSIS ON NON-HYDROCARBON FREE GASES.

CALCULATIONS ARE FOR A RESERVOIR TEMPERATURE OF 715.00 DEG R. REDUCED TEMPERATURES FOR THESE METHODS

ARE: TrA=1.7796
TrB=1.6429
TrC=2.0661

AOF History

Time hrs	Hornr Ratio	Flow Rates Mscf/d	Pressures		Pseudo Gas Pressure (Psi2/μp)£3								
			Psig	Psig2	PrA	1A	2A	PrB	1B	2B	PrC	1C	2C
0.000	0.0000	0.0000	5750.0000	33.0622	7.603	166.539	142.098	6.901	170.494	187.898	8.604	171.415	172.702
6.000	0.0000	29.5000	5600.6992	31.3677	7.406	160.350	136.778	6.722	164.228	181.022	8.381	164.744	165.934
6.000	0.0000	0.0000	5746.6015	33.0234	7.599	166.397	141.976	6.897	170.352	187.742	8.599	171.264	172.548
6.000	0.0000	35.7600	5545.3007	30.7502	7.333	158.056	134.807	6.655	161.905	178.472	8.298	162.274	163.431
6.000	0.0000	0.0000	5742.8007	32.9796	7.594	166.240	141.841	6.892	170.192	187.567	8.593	171.093	172.375
6.000	0.0000	45.5000	5441.8007	29.6128	7.196	153.775	131.129	6.531	157.567	173.708	8.143	157.671	158.771
6.000	0.0000	0.0000	5740.8007	32.9564	7.591	166.157	141.770	6.890	170.108	187.475	8.590	171.004	172.285
6.000	0.0000	52.0500	5369.3007	28.8290	7.100	150.780	128.557	6.444	154.531	170.372	8.034	154.456	155.519
6.000	0.0000	23.8900	5630.6992	31.7046	7.445	161.593	137.846	6.758	165.487	182.404	8.425	166.082	167.291
Build Up													
1.000	188.7999	0.0000	5682.8007	32.2939	7.514	163.752	139.702	6.820	167.674	184.804	8.503	168.409	169.651
3.000	63.5999	0.0000	5694.8984	32.4317	7.530	164.254	140.133	6.835	168.181	185.360	8.522	168.951	170.201
5.000	38.5599	0.0000	5700.5000	32.4956	7.538	164.486	140.333	6.841	168.416	185.619	8.530	169.202	170.455
7.000	27.8285	0.0000	5701.6015	32.5080	7.539	164.531	140.372	6.843	168.463	185.670	8.532	169.250	170.504
11.000	18.0727	0.0000	5702.6992	32.5204	7.541	164.577	140.411	6.844	168.508	185.720	8.533	169.300	170.555
15.000	13.5199	0.0000	5703.8007	32.5333	7.542	164.623	140.451	6.845	168.555	185.771	8.535	169.349	170.604

19.000	10.8842	0.0000	5703.8007	32.5333	7.542	164.623	140.451	6.845	168.555	185.771	8.535	169.349	170.604
23.000	9.1652	0.0000	5704.8984	32.5457	7.544	164.668	140.489	6.847	168.601	185.821	8.536	169.398	170.654
26.100	8.1953	0.0000	5706.0000	32.5581	7.545	164.714	140.529	6.848	168.647	185.872	8.538	169.447	170.704

THE FOLLOWING IS A COMPARISON OF THE DIFFERENCES BETWEEN TWO METHODS
OF CALCULATING PSEUDO GAS PRESSURE. ALL DIFFERENCES ARE EXPRESSED IN PERCENT.

PRESSURES													
PSIA		1A-2A	1A-1B	1A-1C	2A-2B	2A-2C	1B-2B	1C-2C					
5750.0000	14.6757	-2.3751	-2.4187	-2.9283	-32.2315	-21.5375	-10.2079	-0.7506					
5600.6992	14.7004	-2.4187	-2.3765	-2.7400	-32.3473	-21.3167	-10.2255	-0.7227					
5746.6015	14.6762	-2.3765	-2.4350	-2.9249	-32.2346	-21.5333	-10.2083	-0.7499					
5545.3007	14.7095	-2.4350	-2.3771	-2.6683	-32.3903	-21.2335	-10.2321	-0.7133					
5742.8007	14.6769	-2.3771	-2.4655	-2.9195	-32.2372	-21.5272	-10.2090	-0.7492					
5441.8007	14.7267	-2.4655	-2.3779	-2.5333	-32.4710	-21.0800	-10.2442	-0.6978					
5740.8007	14.6772	-2.3779	-2.4874	-2.9171	-32.2388	-21.5243	-10.2091	-0.7489					
5369.3007	14.7386	-2.4874	-2.4098	-2.4382	-32.5261	-20.9730	-10.2511	-0.6882					
5630.6992	14.6955	-2.4098	-2.3947	-2.7781	-32.3244	-21.3609	-10.2225	-0.7279					
5682.8007	14.6867	-2.3947	-2.3913	-2.8441	-32.2840	-21.4378	-10.2163	-0.7374					
5694.8984	14.6848	-2.3913	-2.3892	-2.8596	-32.2741	-21.4562	-10.2143	-0.7397					
5700.5000	14.6840	-2.3892	-2.3892	-2.8669	-32.2703	-21.4647	-10.2143	-0.7405					
5701.6015	14.6838	-2.3892	-2.3891	-2.8680	-32.2698	-21.4658	-10.2141	-0.7407					
5702.6992	14.6835	-2.3891	-2.3886	-2.8699	-32.2687	-21.4684	-10.2138	-0.7413					
5703.8007	14.6833	-2.3886	-2.3886	-2.8705	-32.2674	-21.4686	-10.2135	-0.7410					
5703.8007	14.6833	-2.3886	-2.3884	-2.8705	-32.2674	-21.4686	-10.2135	-0.7410					
5704.8984	14.6832	-2.3884	-2.3876	-2.8724	-32.2667	-21.4713	-10.2132	-0.7416					
5706.0000	14.6830	-2.3876	-2.3875	-2.8735	-32.2658	-21.4726	-10.2135	-0.7418					

THE FOLLOWING IS A COMPARISON BETWEEN TWO METHODS OF CALCULATING PSEUDO GAS PRESSURE USING CARR, KOBAYASHI AND BURROW VISCOSITY CORRELATION, AS METHOD 1, AND USING DEAN AND STIEL VISCOSITY CORRELATION, METHODS 2.

SUBSCRIPT A INCLUDE ALL CORRECTION FACTORS AVAILABLE, WHILE METHODS B, EXCLUDES THESE CORRECTION FACTORS. METHODS C PROVIDES ANALYSIS ON NON-HYDROCARBON FREE GASES.

CALCULATIONS ARE FOR A RESERVOIR TEMPERATURE OF 710.00 DEG R. REDUCED TEMPERATURES FOR THESE METHODS

ARE: TrA=1.7669
TrB=1.6311
TrC=2.0494

AOF History

Time hrs	Homer Ratio	Flow Rates Mscf/d	Pressures			Pseudo Gas Pressure (Psi2/μp)E3							
			Psig	Psig2	PrA	1A	2A	PrB	1B	2B	PrC	1C	2C
0.000	0.0000	0.0000	5750.0000	33.0622	7.603	166.770	142.408	6.901	170.732	188.287	8.604	171.676	173.171
6.000	0.0000	29.5000	5600.6992	31.3677	7.406	160.601	137.102	6.722	164.488	181.437	8.381	165.022	166.409
6.000	0.0000	0.0000	5746.6015	33.0234	7.599	166.630	142.286	6.897	170.589	188.131	8.599	171.525	173.018
6.000	0.0000	35.7599	5545.3007	30.7502	7.333	158.314	135.136	6.655	162.173	178.895	8.298	162.558	163.909
6.000	0.0000	0.0000	5742.8007	32.9796	7.594	166.473	142.152	6.892	170.430	187.957	8.593	171.355	172.845
6.000	0.0000	45.5000	5441.8007	29.6128	7.196	154.044	131.467	6.531	157.850	174.146	8.143	157.967	159.252
6.000	0.0000	0.0000	5740.8007	32.9564	7.591	166.390	142.081	6.890	170.347	187.864	8.590	171.266	172.754
6.000	0.0000	52.0500	5369.3007	28.8290	7.100	151.056	128.901	6.444	154.823	170.822	8.034	154.759	156.001
6.000	0.0000	23.8899	5630.6992	31.7046	7.445	161.840	138.168	6.758	165.743	182.813	8.425	166.357	167.766
Build Up													
1.000	36.0000	0.0000	5682.8007	32.2939	7.514	163.993	140.019	6.820	167.922	185.204	8.503	168.678	170.124
3.000	12.6666	0.0000	5694.8984	32.4317	7.530	164.493	140.449	6.835	168.427	185.758	8.522	169.218	170.672
5.000	8.0000	0.0000	5700.5000	32.4956	7.538	164.724	140.648	6.841	168.661	186.016	8.530	169.468	170.926
7.000	6.0000	0.0000	5701.6015	32.5080	7.539	164.770	140.687	6.843	168.708	186.066	8.532	169.516	170.976
11.000	4.1818	0.0000	5702.6992	32.5204	7.541	164.815	140.726	6.844	168.754	186.116	8.533	169.566	171.026

15,000	3.3333	0.0000	5703.8007	32.5333	7.542	164.861	140.765	6.845	168.800	186.167	8.535	169.615	171.075
19,000	2.8421	0.0000	5703.8007	32.5333	7.542	164.861	140.765	6.845	168.800	186.167	8.535	169.615	171.075
23,000	2.5217	0.0000	5704.8984	32.5457	7.544	164.905	140.804	6.847	168.845	186.217	8.536	169.664	171.125
26,100	2.3409	0.0000	5706.0000	32.5581	7.545	164.951	140.843	6.848	168.892	186.268	8.538	169.713	171.176

THE FOLLOWING IS A COMPARISON OF THE DIFFERENCES BETWEEN TWO METHODS
OF CALCULATING PSEUDO GAS PRESSURE. ALL DIFFERENCES ARE EXPRESSED IN PERCENT.

PRESSURES								
PSIA	1A-2A	1A-1B	1A-1C	2A-2B	2A-2C	1B-2B	1C-2C	
5750.0000	14.6084	-2.3752	-2.9417	-32.2167	-21.6024	-10.2823	-0.8708	
5600.6992	14.6314	-2.4207	-2.7529	-32.3365	-21.3758	-10.3036	-0.8407	
5746.6015	14.6091	-2.3762	-2.9379	-32.2196	-21.5979	-10.2828	-0.8699	
5545.3007	14.6399	-2.4379	-2.6812	-32.3810	-21.2915	-10.3111	-0.8310	
5742.8007	14.6097	-2.3770	-2.9326	-32.2227	-21.5917	-10.2837	-0.8692	
5441.8007	14.6558	-2.4705	-2.5465	-32.4634	-21.1341	-10.3241	-0.8136	
5740.8007	14.6095	-2.3782	-2.9306	-32.2232	-21.5886	-10.2832	-0.8690	
5369.3007	14.6670	-2.4935	-2.4510	-32.5216	-21.0239	-10.3334	-0.8026	
5630.6992	14.6266	-2.4119	-2.7912	-32.3123	-21.4215	-10.2990	-0.8466	
5682.8007	14.6185	-2.3957	-2.8571	-32.2702	-21.5002	-10.2919	-0.8570	
5694.8984	14.6168	-2.3915	-2.8725	-32.2602	-21.5189	-10.2903	-0.8595	
5700.5000	14.6160	-2.3900	-2.8798	-32.2562	-21.5278	-10.2896	-0.8606	
5701.6015	14.6160	-2.3897	-2.8804	-32.2551	-21.5288	-10.2889	-0.8607	
5702.6992	14.6156	-2.3900	-2.8828	-32.2543	-21.5311	-10.2885	-0.8608	
5703.8007	14.6155	-2.3893	-2.8838	-32.2534	-21.5321	-10.2886	-0.8609	
5703.8007	14.6155	-2.3893	-2.8838	-32.2534	-21.5321	-10.2886	-0.8609	
5704.8984	14.6152	-2.3891	-2.8856	-32.2527	-21.5344	-10.2888	-0.8613	
5706.0000	14.6151	-2.3887	-2.8866	-32.2516	-21.5359	-10.2883	-0.8617	

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